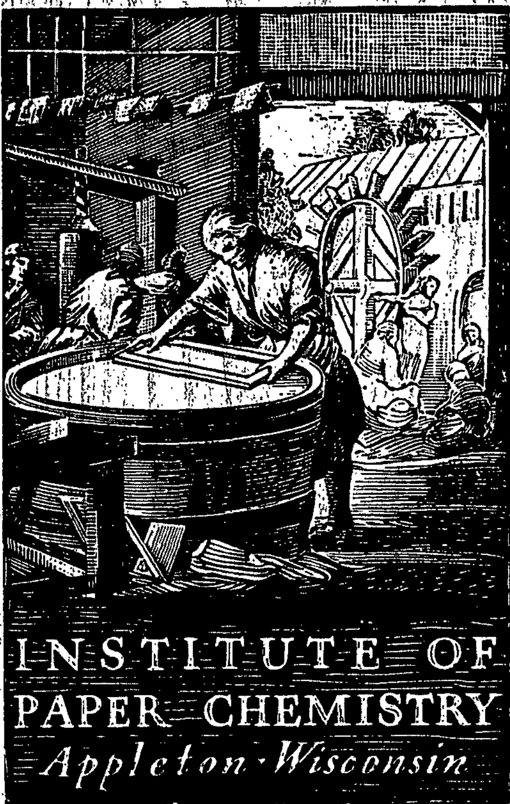

IMPROVED WEIGHT FACTORS FOR FIBER ANALYSIS

Project 3033

Report Four

A Progress Report

to

MEMBERS OF GROUP PROJECT 3033

January 15, 1974

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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Crown Zellerbach Corporation

P. H. Glatfelter Company

Great Northern Paper Company

Hammermill Paper Company

Kimberly-Clark Corporation

The Mead Corporation

St. Regis Paper Company

Scott Paper Company

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

IMPROVED WEIGHT FACTORS FOR FIBER ANALYSIS

SUMMARY

The previous progress reports included: (1) the results of early weight factor determinations made on miscellaneous pulp samples submitted by the participating companies of Project 3033; (2) an extensive study of the weight factors of pulps prepared from (a) various species of southern yellow pine, and (b) hardwood species of red and white oak; and (3) weight factors of pulp samples prepared from hardwood species, other than oak, in which the cooperating companies had expressed the most interest. Progress Report Three also included the development of a set of relative factors based on "vessel counts," for some of the more important North American hardwood species.

The report that follows gives the results of weight factor determinations made on pulp samples prepared from coniferous species, other than the southern yellow pines, in which the project members had expressed a high priority.

The study confirms that there is considerable variation in the weight factors of similarly prepared pulps (i.e., same cook, yield, etc.) derived from different softwood species. Pulps prepared from the Pacific Coast variety of Douglas-fir, for example, have a high coarseness* value and an average weight factor of approximately 1.3-1.4. Pulps prepared from species of northern white-cedar, on the other hand, have low coarseness values and a relative weight factor of approximately 0.5.

*Coarseness is defined as the weight per unit length of fiber, expressed as milligrams/100 m.

The current investigation confirms the supposition that pulps prepared from the Rocky Mountain variety of Douglas-fir [Pseudotsuga menziesii var. glauca (Beissn.) Franco], are not as coarse as the coastal variety (P. menziesii var. menziesii) and, therefore, have lower weight factor values. This was also found to hold more or less true for species of western fir vs. eastern balsam fir (Abies balsamea). The limited data available for the western firs would indicate the possibility that pulps prepared from noble fir are coarser than pulps prepared from either grand fir or silver fir and, therefore, would have higher weight factors.

Pulps prepared from Virginia pine are not as coarse as pulps prepared from other species of southern yellow pine and have, as would be expected, lower weight factor values.

The weight factors determined on different pulp samples prepared from species of western hemlock were less than the TAPPI suggested Standard (T 401 m-60) of 1.2 indicating the possibility that the coarseness value of at least some pulp samples prepared from this species is not as great as originally believed.

The limited data available for several Na bisulfite eastern coniferous pulps (Great Northern) substantiate earlier findings for southern pine pulps (Progress Report Two), i.e., that weight factor is influenced by the degree of cooking.

A set of complete and accurate weight factors for various wood species is an asset to any fiber analyst. The results of fiber analysis work are dependent upon the skill and experience of the operator and his selection of the proper weight factors. When extreme accuracy is required, weight factors should be determined on the same pulps being used in a particular furnish.

INTRODUCTION

An accurate quantitative fiber analysis of a paper, board, or pulp sample makes it desirable to have available for the fiber analyst a set of relative weight factors for the various pulps contained in the furnish being investigated. Weight factors have been a subject of interest for some time. Spence and Krauss (1) first demonstrated that equal areas or equal lengths of different kinds of fibers do not necessarily represent equal weights. Landes (2) and Graff (3) revealed that the weight factors for Scandinavian softwood pulps were higher than those for eastern North American pulps. The Institute of Paper Chemistry has a continuing program relative to weight factor studies on authentic species. Under this program, Graff (4) and later Isenberg and Peckham (5) studied the effect of beating on various pulp samples. More recent investigations (6) revealed that kraft pulps prepared from species of coastal and interior varieties of Douglas-fir have weight factors of 1.45 and 1.0, respectively.

The principal objectives of Project 3033 were to: (1) examine the weight factors of various pulps, particularly softwood and hardwood pulp samples prepared from different tree species of interest to the participating companies of the project; (2) examine the effect that geographic location, cook, yield, etc., may have on the weight factor; (3) investigate weight factors for pulps prepared by the more recently developed pulping processes of interest to co-operators of the project; (4) develop a set of relative factors for hardwood species based on vessel counts.

The weight factors of several authentic pulp samples submitted for investigation by the cooperators of the project were reported in Progress Report One.

An extensive study was made and the results reported in Progress Report Two on the weight factors of different pulp samples prepared from various species of southern yellow pine and species of red and white oak. Progress Report Three reported the weight factors of the more common North American hardwood pulp species, other than species of oak. A set of relative factors based on "vessel counts" was also developed and presented in this report.

The final report of the program includes determinations made on high priority softwood pulps prepared from species of Pacific and Rocky Mountain types of Douglas-fir, the western firs, western hemlock, western larch, western red-cedar, lodgepole pine, jack pine, Virginia pine, red pine, eastern larch, eastern hemlock, white spruce, balsam fir, and northern white-cedar.

EXPERIMENTAL METHODS AND MATERIALS

METHODS

Standard Weight Factors

The same methods for weight factor determinations were employed as outlined in the previous reports and were as follows.

A fifty-fifty mixture by weight of a standard pulp (i.e., cotton linters — J. H. Munktells Swedish Filtering Paper for Chromatography) with a known relative weight factor of 1.1 and the pulp under investigation are prepared by thoroughly mixing in a large Erlenmeyer flask. This fiber suspension is poured into six test tubes and each is diluted to the desired consistency (i.e., approximately 0.05%). Standard slides are prepared (a one-inch square field of each end of every slide) from each of the six pulp mixtures and the fibers mounted and differentially stained with Graff "C" stain (refer to TAPPI Standard T 401 m-60). The fibers are counted at a magnification of 100 diameters with the aid of a binocular microscope equipped with a mechanical stage and an eyepiece with a pointer. The fiber field is moved horizontally and all the fibers counted as they pass under the end of the pointer. The one-square-inch field is scanned five times on lines 4 mm apart for a count which usually totals between 200-300 fibers. Both sides of the six slides are examined in this manner for each determination. Since the weight factor for the standard pulp is known, the relative weight factor for the pulp being examined is readily calculated.

SAMPLES

All remaining pulps prepared from softwood species of most interest to the participating companies were investigated in this present study. Some of the pulps were submitted by project cooperators while others were laboratory pulps prepared under controlled conditions at The Institute of Paper Chemistry. A list of these pulps and all available relative data have been recorded in Tables I, II, and III. The known cooking conditions for most of these pulps are given in Table IV.

TABLE I

PULPS SUBMITTED BY THE COOPERATING COMPANIES[a]

Pulp No.	Cooperating Company	Wood Species	Origin	Cook	Total Yield, %	Screened Yield, %	Kappa No.
1	Riegel	Douglas-fir (#131)	Burney, Calif.	Kraft (Cook #52)	--	--	37
2	Hammermill	Lodgepole pine	Montana	Kraft	--	--	20
3	Hammermill	Tamarack	Michigan	Kraft	--	--	21
4	Great Northern	Tamarack	--	Na-bisulfite (Cook #684)	44.5	--	--
5	Hammermill	Jack pine	North Central	Kraft	--	--	19
6	Riegel	Jack pine (#403)	Dryden, Ontario	Kraft (Cook #63)	--	--	40
7	Scott	Jack pine	Muskegan, Mich.	Kraft (Cook #72-42)	46.6	45.4	20.6
8	Scott	Red pine	Muskegan, Mich.	Kraft (Cook #72-43)	48.4	45.9	21.0
9	Great Northern	N. white-cedar (#654)	--	Kraft	47.0	--	--
10	Great Northern	Eastern hemlock	--	Na-bisulfite (Cook #903A)	49.6	--	--
11	Great Northern	Eastern hemlock	--	Na-bisulfite (Cook #1018A)	73.39	72.62	--
12	Great Northern	Spruce	Maine	Na-bisulfite (Cook #649)	50.5	--	--
13	Great Northern	Spruce	Maine	Na-bisulfite (Cook #808)	50.1	--	--
14	Great Northern	Balsam fir	Maine	Na-bisulfite (Cook #650)	50.3	--	--
15	Great Northern	Balsam fir	Maine	Na-bisulfite (Cook #1017B)	75.54	74.54	--

[a]Crown Zellerbach pulp samples recorded in Table II.

TABLE II

PULPS SUBMITTED BY CROWN ZELLERBACH CORPORATION

Species	Western red-cedar, *Thuja plicata*	Western hemlock, *Tsuga heterophylla*	Noble fir, *Abies procera*	Silver fir, *Abies amabilis*	Grand fir, *Abies grandis*	Douglas-fir, *Pseudotsuga menziesii*
Location	Clackamas, Oregon	Wauna, Oregon	Mt. Adams, Wash.	Mt. Adams, Wash.	Mt. Adams, Wash.	Vernonia, Oregon
Township	6S	8N	7N	7N	7N	4N
Range	3E	6W	10E	10E	11E	3W
Section	4	31	5	5	17	18
Elevation, ft	1200	800	4000	4000	4000	800
Tree age, yr	67	46	160	85	50	52
Tree height, ft	61	85	80	85	87	80
Diam. (4.5 ft), inch	16.5	13.0	14.0	13.0	13.3	13.5
Log section	All 8 ft sections taken above first 16 ft log					
Ring count	57	30	147	58	25	28
Sp.gr., g/cc	0.317	0.347	0.355	0.303	0.295	0.395
lb/ft^3	19.8	21.7	22.2	18.9	18.4	24.7
Bulk chip density, OD no./ft^3						
Unsettled	6.6	7.3	8.1	6.2	6.2	8.2
Settled	8.3	9.5	10.3	7.9	7.8	10.5
Cook number	K-811	K-812	K-813	K-817	K-820	K-821
Active alkali, % bow	16	16	15½	15½	16	15½
Permanganate no.	27.3	28.9	24.9	26.7	26.2	28.1
Total yield, % bow	48.6	46.4	49.0	47.1	47.3	47.0
Screened yield, % bow	48.1	45.5	48.2	46.6	46.4	46.0
Screenings, % of total	1.09	2.08	1.14	1.06	1.92	2.05

TABLE III

KRAFT PULPS PREPARED FROM ACQUIRED WOOD SAMPLES AND PULPED AT THE INSTITUTE OF PAPER CHEMISTRY

Pulp No.	Wood Species	Origin	Tree Age, yr	Height, ft	Dbh, inch	Total Yield, %	Kappa No.
1[a]	Douglas-fir (3033-28)	Oregon	70	87	10.5	41.6	20.5
2	Douglas-fir (3033-33)	Colorado	63	28	6.9	42.3	22.6
3	Jack pine (3033-12)	N. Wisconsin	25	33	7.2	44.5	22.2
4[a]	Western hemlock (3033-27)	Oregon	46	79	10.6	43.6	31.2
5[a]	Western hemlock (3033-37-38)	Washington	33	32	8.3	47.6	64.8
6[a]	Western larch (3033-29)	Washington	60	82	12.0	44.7	23.5
7	Lodgepole pine (3033-34)	Colorado	74	34	7.5	44.4	19.5
8	W. spruce (3033-8)	N. Wisconsin	40	38	7.0	40.7	20.8
9	Balsam fir (3033-30)	Wisconsin	39	45	7.0	48.1	29.7
10	Virginia pine (3033-35)	Pennsylvania	21	--	5.8	47.3	51.7
11	Virginia pine (3033-36)	N. Carolina	25	50	6.2	47.6	55

[a]Composite of two trees.

TABLE IV

COOKING CONDITIONS

A. Crown Zellerbach Pulps

Kraft cooking

Chips were subjected to standard kraft cooking in a 2½ cubic foot rotary digester. Cooking conditions follow:

Liquor/wood ratio	5/1
Active alkali, 70 bow[a]	15½-16[b]
Time to temp., min	60
Time at temp., min	105
Cooking temp., °F	345

[a]Active alkali as Na_2O on weight of ovendry wood. Sulfidity was about 25% of active.
[b]Varied to obtain a screened pulp permanganate number of 25-30.
Cooks were blown at full pressure, washed, screened 0.008 inch, and centrifuged in the usual manner.

B. Great Northern Pulps

High yield bisulfite pulps

Chemical, %	18% SO_2 as $Mg(OH)_2$ on OD wood basis
Liquor/wood ratio	4/1
Top temperature	155°F
Top pressure	107 psig
Hold period	55 min at 140°C

Chips presteamed for 15 min prior to adding liquor.

C. Scott Pulps

Kraft cook

Chemical, %	17.0
Sulfidity, %	25±1
Liquor/wood ratio	4/1
To top temperature, min	60
At top temperature, min	90
Top temp., °C	174
Maximum pressure	130
Blow down	Rapid cool

D. The Institute of Paper Chemistry Pulps

Digester charge, g o.d.	50
Liquor-to-wood ratio	6/1
Active alkali as Na_2O, %	20
Sulfidity, %	25
Time to max. temperature, min	90
Time at max. temperature, min	75
Maximum temperature, °C	175

DESCRIPTION OF WOOD SPECIES AND RESULTS OF WEIGHT FACTOR DETERMINATIONS

The same format established in previous reports was used to present the data in the following section. A brief description of the general characteristics, gross and minute features (7,8) of the softwood species examined during the current phase of the program are recorded. Photomicrographs of the transverse wood surface and also of a pulp prepared from each wood species accompany most of the descriptions. The characterization of each species is followed by the results of weight factor determinations made on the pulp samples.

DOUGLAS-FIR [Yellow Fir, Red Fir (*Pseudotsuga menziesii* (Mirb.) Franco]

General Description and Minute Anatomy

There are two types of Douglas-fir species, the inland or Rocky Mountain variety [*P. menziesii* var. *glauca* (Beissn.) Franco] and the Pacific Coast variety (*P. menziesii* var. *menziesii*). The range of the two varieties is shown in Fig. 1. The wood is moderately light (sp.gr. approximately 0.43 green, 0.48 ovendry — Rocky Mountain type) to moderately heavy (sp.gr. approximately 0.45 green, 0.51 ovendry — Pacific Coast type). The growth rings are very distinct, frequently wavy, delineated by a pronounced band of darker latewood, narrow (yellow fir) to very wide (red fir). The earlywood is usually several times wider than the band of latewood; the transition is generally abrupt (in wide rings sometimes more or less gradual). The latewood zone is very narrow in slow growth stock to very wide and dense in faster growing trees. The rays are very fine and not visible (cross section) to the naked eye. Longitudinal and transverse resin canals are present. The longitudinal canals are barely visible or indistinct to the naked eye, confined largely to the outer half of the growth ring. They may be sparse and scattered or numerous and exhibit more or less a tendency toward alignment

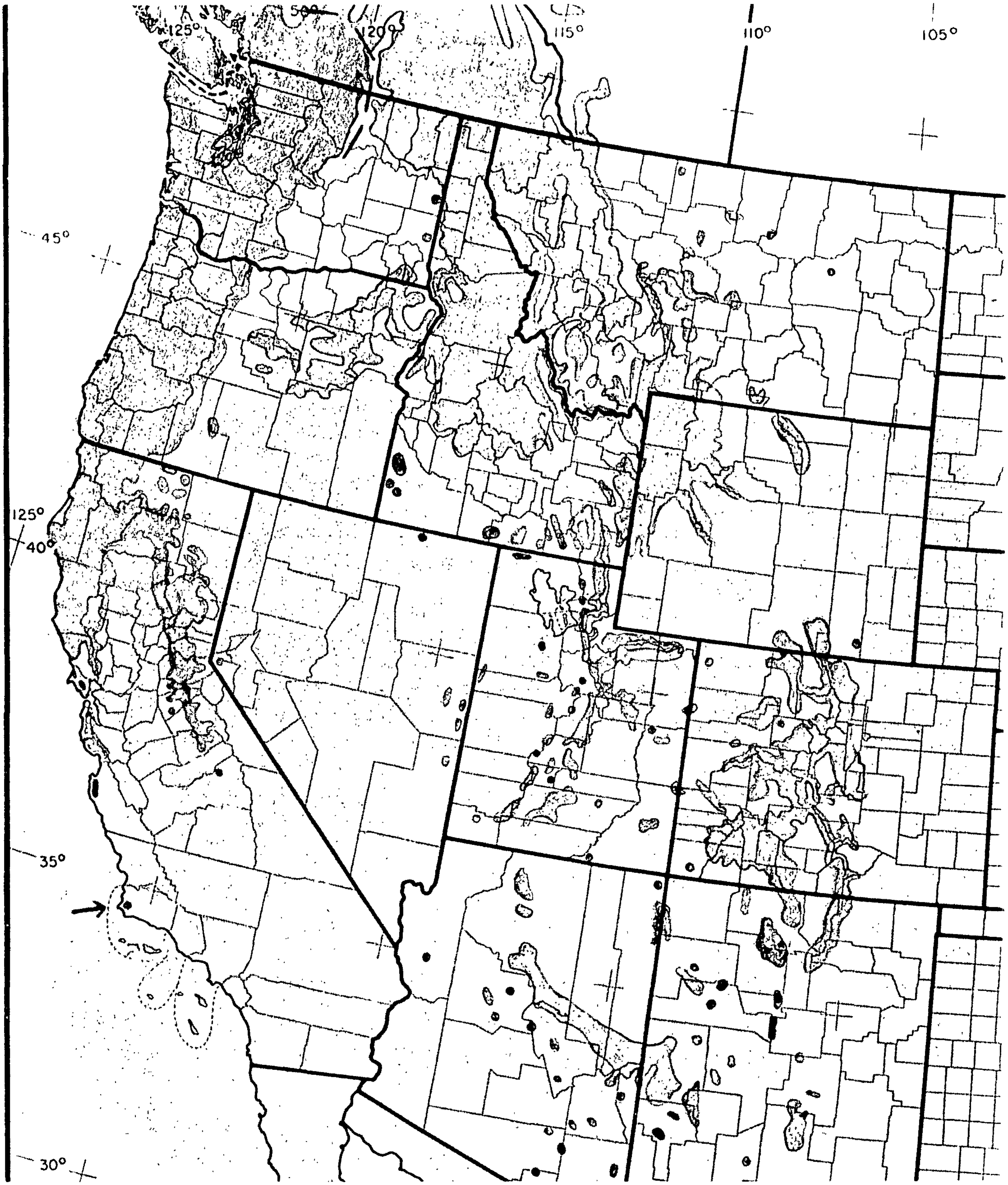

Figure 1. Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco. The Broken Line Separates Eastward the Rocky Mountain Variety, P. menziesii var. glauca Beissn.) Franco, and Westward the Coast Variety, P. menziesii var. menziesii

in tangential rows of 2-30+. The transverse canals are smaller than the longitudinal canals, not visible or barely visible with a hand lens on the tangential surface. The tracheids are up to 55 (average 35-45) μm in diameter and 3.9 mm (1.7 to 7.0 mm) in length. Close bands of spiral thickening characterize nearly all tracheids. Rays are of two types, uniseriate or rarely in part biseriate and fusiform. The uniseriate rays are numerous and 1-25 cells in height. The fusiform rays are scattered, with one or very rarely two, transverse resin canals, 3-5 seriate through the central thickened portion, tapering above and below to uniseriate margins up to 16+ cells in height. Ray tracheids are present in both types of rays and are marginal and very rarely interspersed. The volume occupied by the rays is approximately 7%. The resin canals have thick-walled epithelium and are constricted at intervals and occasionally with tylosoids in the heartwood. The longitudinal canals have a maximum diameter of 150 (average 60-90) μm while the transverse canals are much smaller (usually less than 25 nm). The volume occupied by the resin canals is approximately 0.2%. Longitudinal parenchyma is marginal and very sparse, or wanting.

A photomicrograph (SEM) of the transverse surface area of Douglas-fir is illustrated in Fig. 2. The photomicrograph illustrates the extreme difference in cell wall thickness and wood density between early- and latewood tracheids which is characteristic of the species. The transition from earlywood to latewood is fairly abrupt. Resin canals are generally confined to the outer half of the growth ring.

Weight Factor Determination

The results of weight factor determinations made on various pulp samples prepared from species of Douglas-fir are listed in Table V. Pulps prepared from the coastal form of this species had, in every case, higher weight factor values than pulp samples prepared from the inland form. Factors of 1.4 and 0.9 are recommended for the Pacific Coast type and the Rocky Mountain type, respectively. The 1.4 factor agrees favorably with the suggested factor of 1.5 in the TAPPI Standard. The factor of 0.9 for the inland form of this species, however, is considerably lower than the suggested standard and should be used for more accurate results in quantitative determinations of furnishes containing this variety of the species.

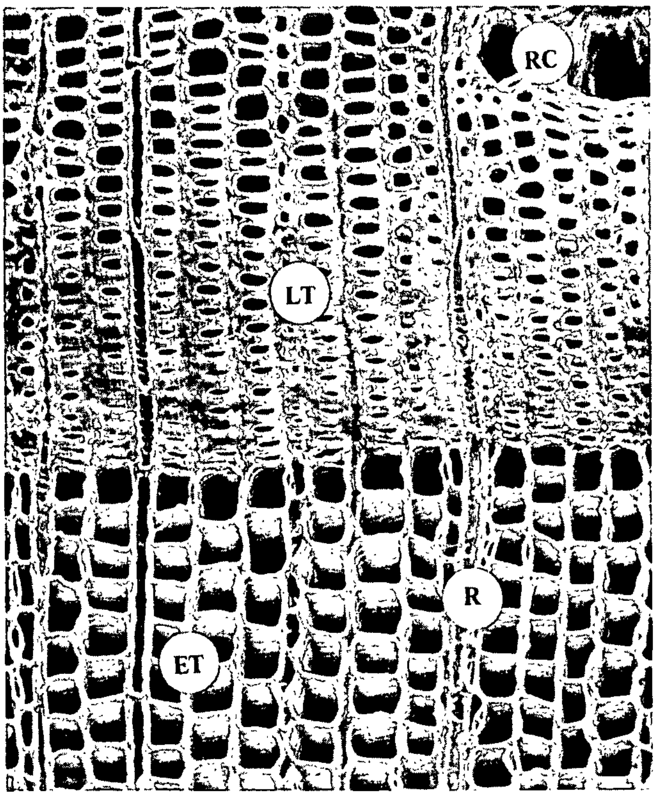

Figure 2. Photomicrograph (SEM) of Transverse Surface of Douglas-fir, Colorado (IPC 3033-33). Latewood Tracheids (LT), Earlywood Tracheids (ET), Resin Canal (RC), Ray (R). Magnification 200 Diameters

Photomicrographs of pulp furnishes prepared from species of Douglas-fir are illustrated in Fig. 3 (Rocky Mountain variety) and Fig. 4 (Pacific Coast variety). Pulps prepared from the coastal variety of the species are considerably coarser than the inland or Rocky Mountain variety and have 40-50% higher weight factor values.

TABLE V

WEIGHT FACTORS — DOUGLAS-FIR
(ROCKY MOUNTAIN TYPE AND PACIFIC COAST TYPE)

No.	Pulp Sample	Type	Weight Factors Analyst A	B	Av.
1	Douglas-fir — unbleached kraft — Riegel No. 131	Coastal	1.30	1.38	1.34
2	Douglas-fir — unbleached kraft — Crown Zellerbach	Coastal	1.13	1.09	1.11
3	Douglas-fir — unbleached kraft — IPC No. 3033-28	Coastal	1.47	1.48	1.48
4	Douglas-fir — kraft — (IPC Project 1499)	Coastal	1.45	--	1.45
5	Douglas-fir — unbleached kraft — IPC No. 3033-33	Inland	0.77	0.77	0.77
6	Douglas-fir — kraft — (IPC Project 1499)	Inland	1.0	--	1.0

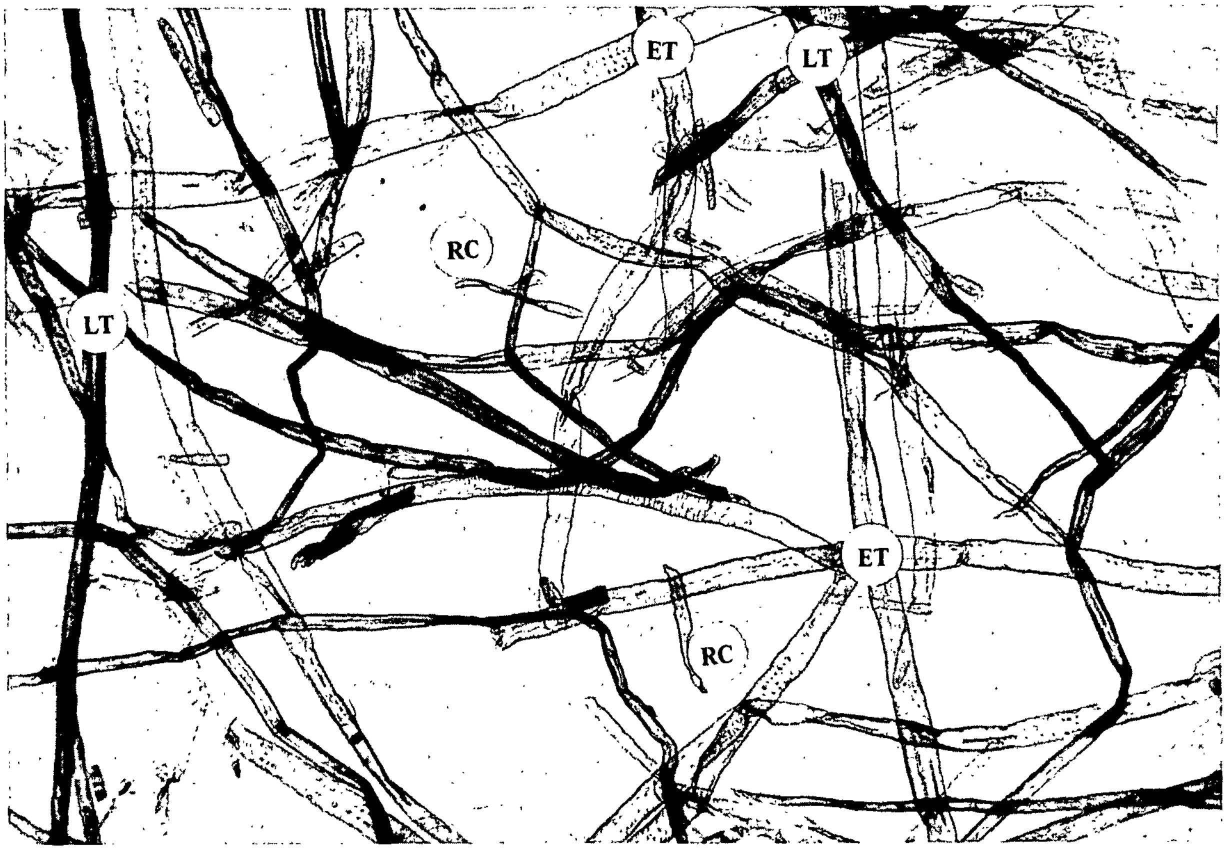

Figure 3. Pulp Sample of Douglas-fir, Colorado (IPC 3033-33) — Unbleached Kraft. Yield 42.3%. Kappa No. 22.6. Weight Factor 0.77. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

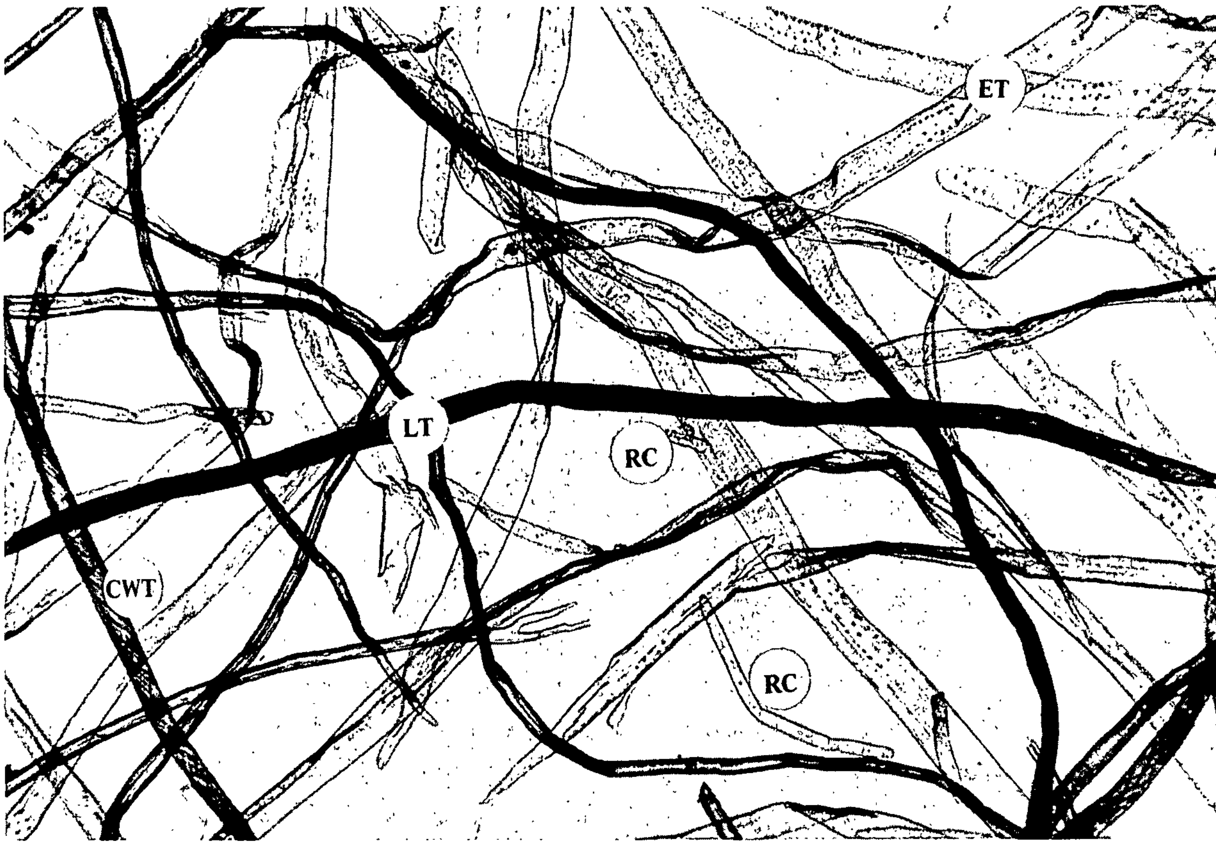

Figure 4. Pulp Sample of Douglas-fir, Oregon (Crown Zellerbach) — Unbleached Kraft. Screened Yield 48.1%. Kappa No. 47.6. Weight Factor 1.11. Latewood Tracheids (LT), Earlywood Tracheids (ET), Compression Wood Tracheid (CWT), Ray Cells (RC). Magnification 90 Diameters

WESTERN FIRS
White Fir [*Abies concolor* (Gord. & Glend.) Lindl.]
Grand Fir [*Abies grandis* (Dougl.) Lindl.]
Subalpine Fir [*Abies lasiocarpa* (Hook.) Nutt.]
California Red Fir (*Abies magnifica* A. Murr.)
Noble Fir (*Abies procera* Rehd.)
Pacific Silver Fir [*Abies amabilis* (Dougl.) Forbes]

General Description and Minute Anatomy

The wood of the western firs is light (sp.gr. approximately 0.35-0.37 green, 0.30-0.45 ovendry; occasionally as high as 0.56 in noble fir). The growth rings are distinct, delineated by a band of darker latewood, medium wide to wide (3-4 per inch) or narrow in the outer portion of mature trees. The earlywood zone usually occupies one-half or more of the ring. The transition from early- to latewood is gradual. Rays are very fine, not distinct to the naked eye on the cross section. Normal resin canals are wanting but longitudinal wound (traumatic) canals are sometimes present. The tracheids are up to 60 (average 35-45) μm in diameter and 3.4 mm in length. The rays are uniseriate (or occasionally in part biseriate in _Abies magnifica_ A. Murr.), variable in height (1-30 plus cells), and consist wholly of ray parenchyma. Longitudinal parenchyma is sparse or absent. The woods of the western firs resemble balsam fir [_Abies balsamea_ (L.) Mill]. The true fir (_Abies_ spp.) cannot be separated on the basis of wood anatomy.

Weight Factor Determinations

Weight factor determinations made on pulp samples prepared from species of western fir are recorded in Table VI.

TABLE VI

WEIGHT FACTOR DETERMINATIONS FOR WESTERN FIR PULP SAMPLES

Pulp Samples	Weight Factor Determinations, Analyst A	Analyst B	Av.
1. Grand fir (Mt. Adams, Wash.) — unbleached kraft — Crown Zellerbach Corp.	0.92	0.89	0.90
2. Noble fir (Mt. Adams, Wash.) — unbleached kraft — Crown Zellerbach Corp.	1.23	1.26	1.24
3. Silver fir (Mt. Adams, Wash.) — unbleached kraft — Crown Zellerbach Corp.	0.93	0.97	0.95

Photomicrographs of pulps prepared from the true firs (_Abies_ spp.) are illustrated in Fig. 5 and 6.

The factors of 0.90 and 0.95 determined for the pulp samples prepared from species of grand fir and silver fir, respectively, compare favorably with the suggested factor of 0.90 listed in TAPPI Standard T 401 m-60. The investigation

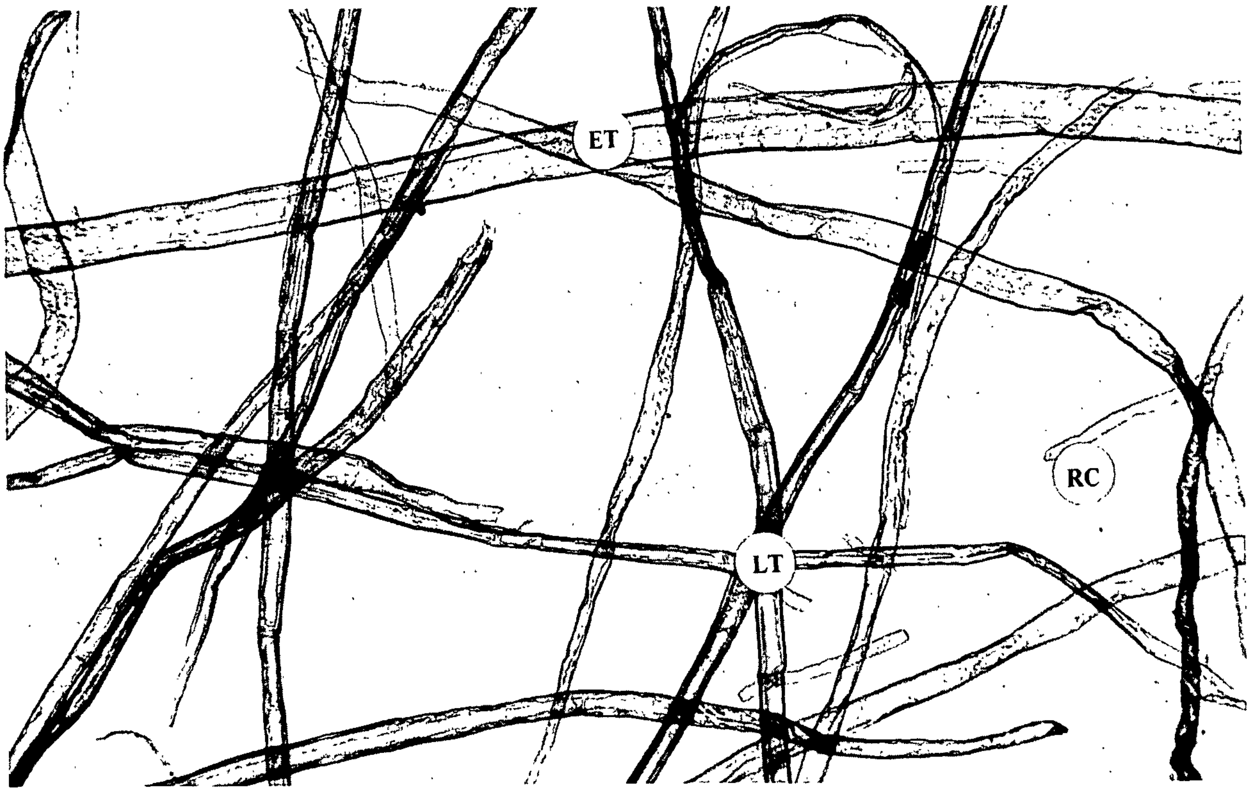

Figure 5. Pulp Sample of Noble Fir, Wash. — Unbleached Kraft. Screened Yield 48.2%. Kappa No. 38.8. Weight Factor 1.24. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

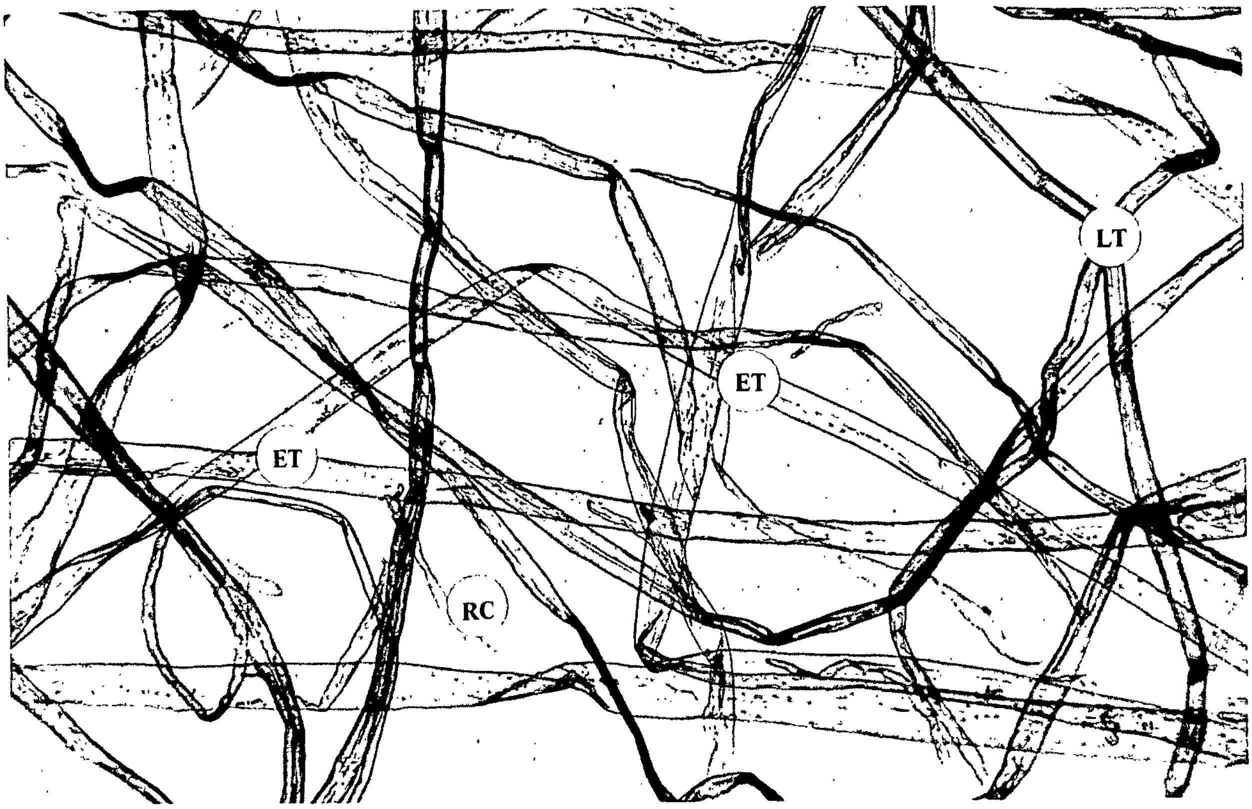

Figure 6. Pulp Sample of Silver Fir, Wash. — Unbleached Kraft. Screened Yield 46.0%. Kappa No. 43.5. Weight Factor 0.95. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

was limited but there is an indication that pulps prepared from noble fir are possibly coarser and have a higher weight factor value than pulps prepared from other species of western firs.

WESTERN HEMLOCK, WEST COAST HEMLOCK [*Tsuga heterophylla* (Raf.) Sarg.]

General Description and Minute Anatomy

The wood of western hemlock is moderately light (sp.gr. approximately 0.42 green, 0.47 ovendry). The growth rings are distinct, delineated by a band of darker latewood, narrow to wide but generally narrower and more uniform in width than in eastern hemlock. The earlywood zone usually occupies at least two-thirds or more of the annual ring and is lighter and less dense than the latewood. The rays are fine and not distinct on the transverse surface with the naked eye. Normal resin canals are wanting and traumatic resin canals or wound canals are sometimes present. The tracheids are up to 50 (average 30-40) μm in diameter and average 4.2 mm (1.8 to 6.0 mm) in length. Volume occupied by the tracheids is > 90%. The rays are uniseriate or very rarely biseriate, 1 to 16+ cells in height. Ray tracheids are present and usually restricted to one row on the margins of the ray. Volume occupied by the rays is < 10%.

A photomicrograph (SEM) of a transverse surface area of western hemlock is illustrated in Fig. 7.

Weight Factor Determination

The results of weight factor determinations made on western hemlock pulp samples are recorded in Table VII.

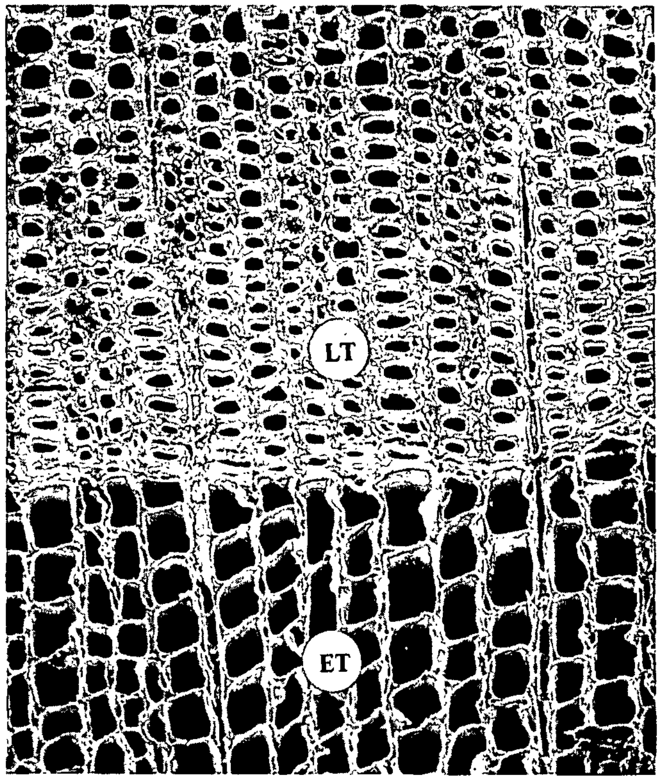

Figure 7. Photomicrograph (SEM) of Transverse Surface of Western Hemlock, Wash. (IPC 3033-37 and 38). Latewood Tracheids (LT), Earlywood Tracheids (ET). Magnification 200 Diameters

TABLE VII

WEIGHT FACTOR DETERMINATIONS FOR WESTERN HEMLOCK PULP SAMPLES

Pulp Samples	Weight Factor Determination, Analyst A	Analyst B	Av.
1. Western hemlock (Oregon) — unbleached kraft — Crown Zellerbach Corp.	1.03	0.97	1.00
2. Western hemlock (Oregon) — unbleached kraft — IPC No. 3033-27	0.80[a]	0.79[b]	0.80
3. Western hemlock (Wash.) — unbleached kraft — IPC No. 3033-37-38	0.83	0.84	0.84

[a]A weight factor of 0.73 was determined for this sample by Analyst A on a second trial.

[b]A factor of 0.71 was determined for this sample by Analyst B using white birch kraft pulp (IPC 3033-1) as a standard with a factor of 0.52 (western hemlock count 1148 vs. white birch count of 1573).

The results of weight factor determinations on all pulp samples prepared from species of western hemlock were less than the TAPPI suggested Standard of 1.2. The investigation was limited but a weight factor of 0.9-1.0 might possibly be a better relative value for most pulps prepared from this species.

Photomicrographs of fiber furnishes of pulp samples prepared from western hemlock are illustrated in Fig. 8 and 9.

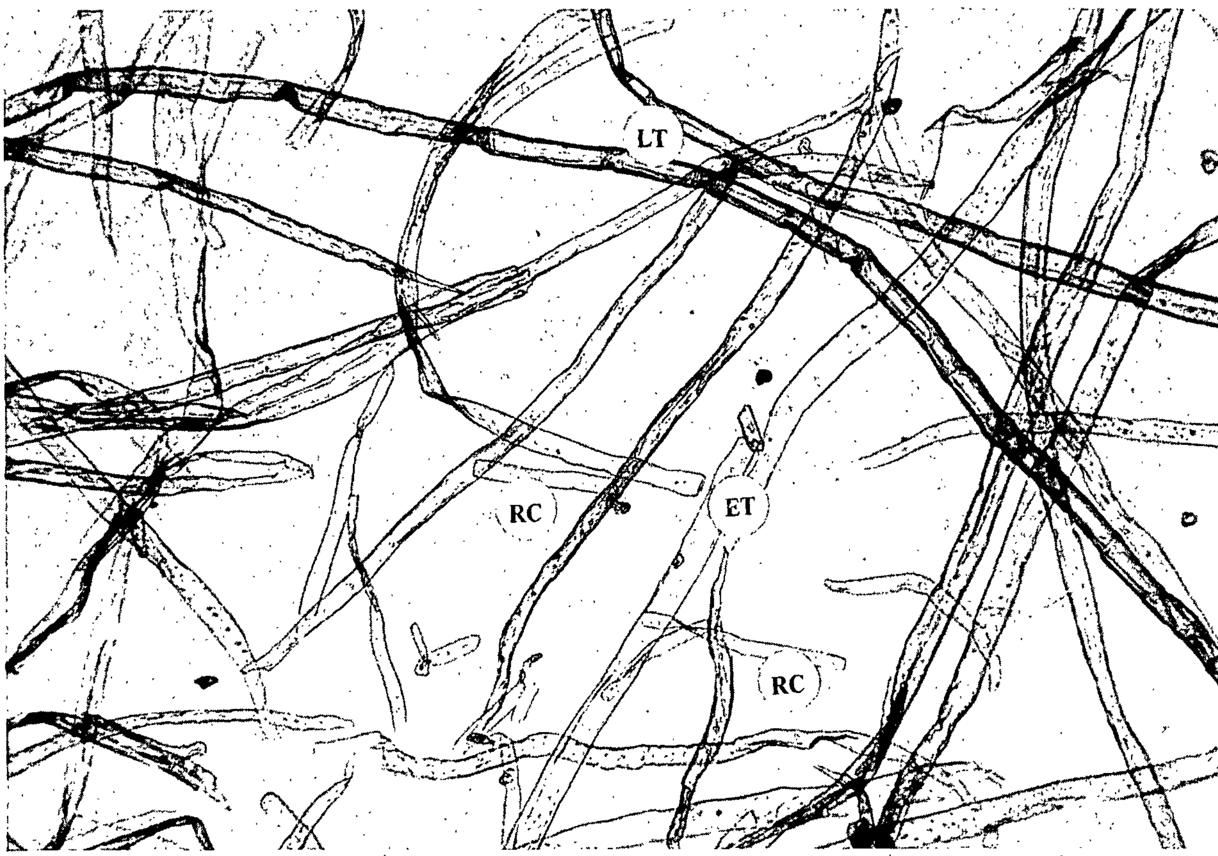

Figure 8. Pulp Sample of Western Hemlock, Oregon (Crown Zellerbach) — Unbleached Kraft. Screened Yield 45.5%. Kappa No. 49.8. Weight Factor 1.0. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

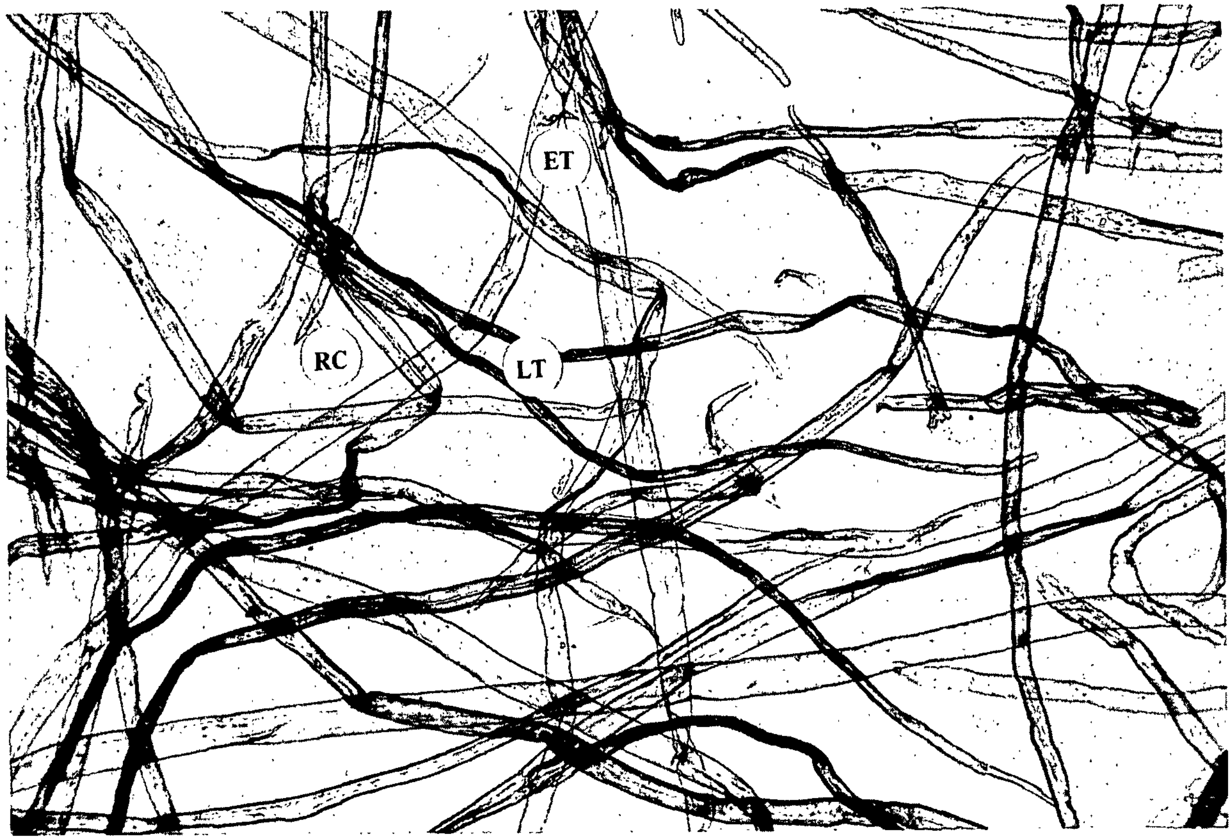

Figure 9. Pulp Sample of Western Hemlock, Wash. (IPC 3033-37-38) — Unbleached Kraft. Yield 47.6%. Kappa No. 64.8. Weight Factor 0.84. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

WESTERN LARCH (Larix occidentalis Nutt.)

General Description and Minute Anatomy

The wood of western larch is moderately heavy (sp.gr. approximately 0.48 green, 0.55 ovendry). The growth rings are distinct, delineated by a pronounced band of darker latewood, which is generally very narrow (30-60 per inch) and quite uniform in width. The earlywood zone usually constitutes two-thirds or more of the ring. The rays are very fine, not distinct on the cross section to the naked eye. Longitudinal resin canals have a maximum diameter of 135 µm (average 60 to 90), not visible to the naked eye or appearing as whitish or dark flecks, sparse, confined mostly to the narrow bands of latewood, solitary or 2 to several contiguous in the tangential plane. The smaller transverse canals (usually less than

25 µm in diameter) appear with a hand lens as somewhat broader whitish rays spaced at irregular intervals on the transverse surface. They are not visible or barely visible with a hand lens on the tangential surface. The resin canals have thick-walled epithelium occasionally with tylosoids in the heartwood. Volume occupied by resin canals is approximately 0.1%. The tracheids are up to 60 (average 40-50) µm in diameter and average approximately 3.3 mm in length. The volume occupied by the tracheids is 89.0%. Longitudinal parenchyma is marginal and very sparse or wanting. Rays are of two types, uniseriate or rarely in part biseriate, and fusiform. The uniseriate rays are numerous and 1-20+ cells in height. The biseriate rays are very sparse and scattered or wanting. Fusiform rays are 2-3 seriate through the central thickened portion, tapering above and below to uniseriate margins up to 20+ cells in height. Ray tracheids are present in both types of rays, marginal and rarely interspersed. Ray volume is 10.0%.

A photomicrograph (SEM) of the transverse surface area prepared from a wood sample of western larch is illustrated in Fig. 10.

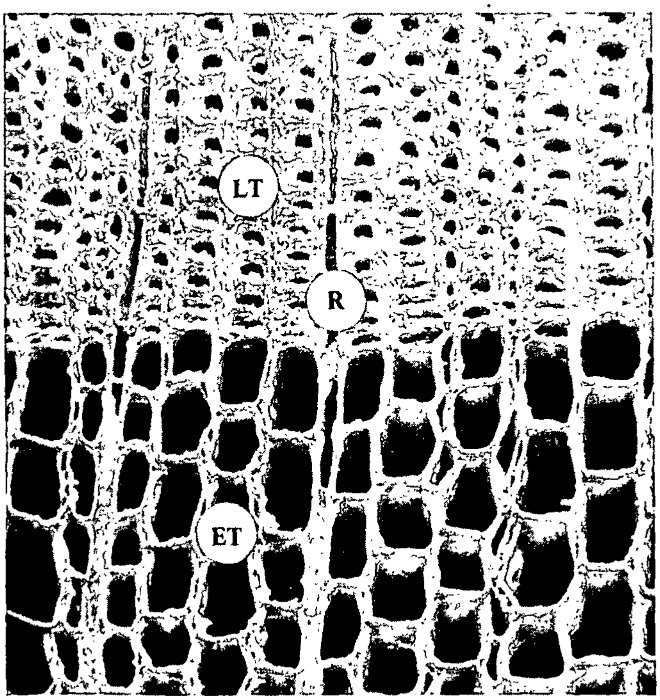

Figure 10. Photomicrograph (SEM) of Transverse Surface of Western Larch, Wash. (IPC 3033-29). Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray (R). Magnification 200 Diameters

Weight Factor Determination

The results of a weight factor determination made on a pulp sample prepared from western larch are presented in Table VIII.

TABLE VIII

WEIGHT FACTOR DETERMINATION ON WESTERN LARCH PULP

Pulp Sample	Weight Factor Determination		
	Analyst		
	A	B	Av.
Western larch (Wash.) — unbleached kraft — IPC No. 3033-29	1.20	1.22	1.21

Pulps prepared from western larch are coarser than pulps prepared from eastern larch and have higher weight factor values.

A photomicrograph of a pulp furnish prepared from western larch is illustrated in Fig. 11.

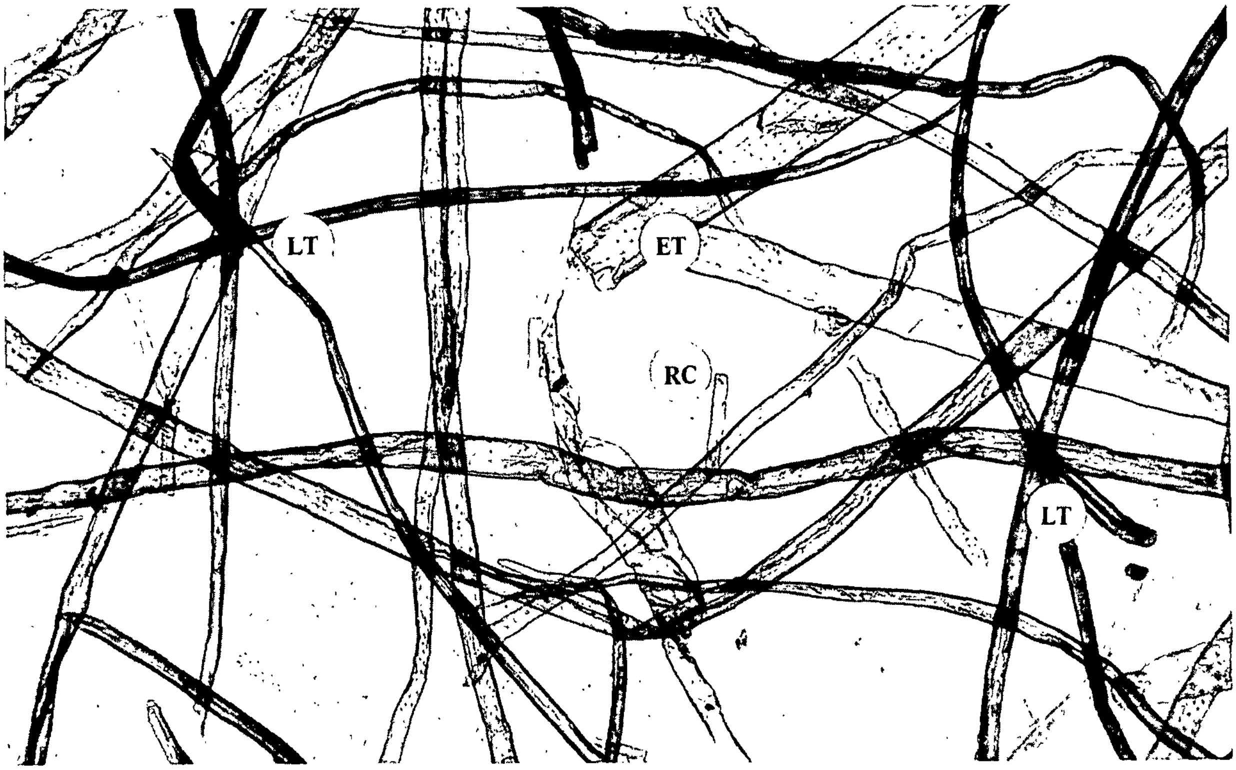

Figure 11. Pulp Sample of Western Larch, Wash. (IPC 3033-29) — Unbleached Kraft. Yield 44.7%. Kappa No. 23.5. Weight Factor 1.21. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameter

WESTERN RED-CEDAR, GIANT ARBORVITAE
(*Thuja plicata* Donn)

General Description and Minute Anatomy

The wood of western red-cedar is light (sp.gr. approximately 0.31 green, 0.33 ovendry). The growth rings are distinct and generally quite conspicuous, delineated by a darker band of latewood which is narrow to fairly wide. The earlywood zone occupies most of the ring. The rays are fine, forming a close, inconspicuous fleck on the quarter surface. Resin canals are absent. The tracheids are up to 45 (average 30-40) μm in diameter. Longitudinal parenchyma is apotracheal-diffuse or occasionally exhibiting more or less a tendency toward zonation. The cells are usually conspicuous because of their gummy contents. The rays are uniseriate or rarely with paired cells, 1 to 12+ cells high, consisting entirely of ray parenchyma or very rarely with ray tracheids. Gummy infiltration is fairly abundant in the ray cells of the heartwood.

Weight Factor Determination

The results of a weight factor determination made on a sample of western red-cedar pulp are recorded in Table IX.

TABLE IX

WEIGHT FACTOR DETERMINATION FOR WESTERN RED-CEDAR PULP SAMPLE

Pulp Sample	Weight Factor Determination, Analyst A	Analyst B	Av.
Western red-cedar (Oregon) — unbleached kraft — Crown Zellerbach Corporation	0.70	0.69	0.70

Pulps prepared from species of cedar have relatively low coarseness and weight factor values.

A photomicrograph of a pulp furnish prepared from western red-cedar is illustrated in Fig. 12.

Figure 12. Pulp Sample of Western Red-Cedar, Oregon (Crown Zellerbach) — Unbleached Kraft. Screened Yield 48.1%. Kappa No. 45.2. Weight Factor 0.70. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

LODGEPOLE PINE (Pinus contorta Dougl.)

General Description and Minute Anatomy

The wood of lodgepole pine is moderately light (sp.gr. approximately 0.38 green, 0.43 ovendry). The growth rings are distinct, delineated by a band of darker latewood. The earlywood zone is wide or narrow (outer rings of mature trees) and the transition from early- to latewood is more or less abrupt. The rays are very fine on the cross section and not visible to the naked eye. Longitudinal resin canals have a maximum diameter of 110 (average 80-90) µm while the transverse canals are less than 50 µm in diameter. The resin canals have thin-walled epithelium and are frequently occluded with tylosoids in the heartwood. The tracheids are up to 55 (average 35-45) µm in diameter and 3.1 mm in length. Rays are of two types, uniseriate and fusiform. The uniseriate rays are numerous, 1-8+ cells in height. The fusiform rays are scattered, with a transverse resin canal, 2-3 seriate through the central thickened portion, tapering above and below to uniseriate margins, up to 30+ cells in height. Ray tracheids are present in both types of rays. Volume occupied by the rays is approximately 5.7%. Parenchyma cells are absent.

A photomicrograph (SEM) of the transverse surface area prepared from a wood sample of lodgepole pine is illustrated in Fig. 13.

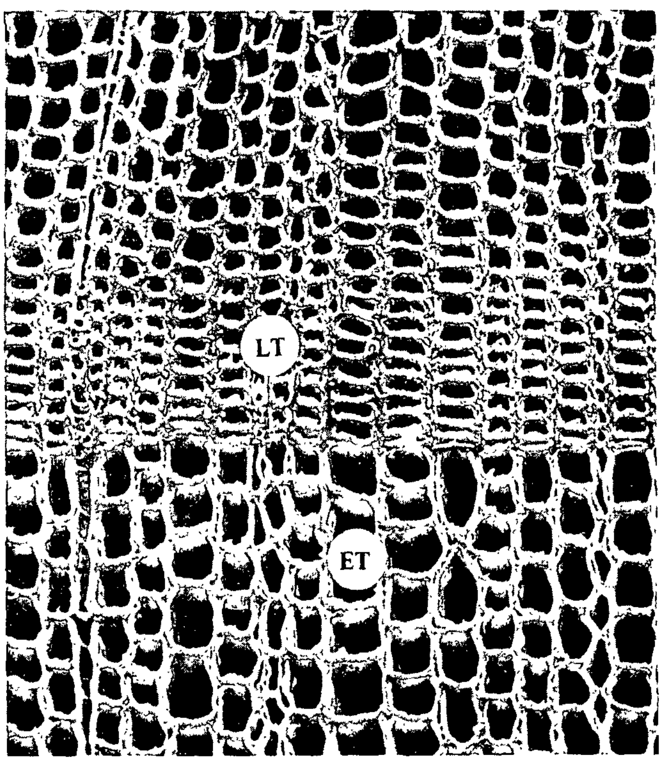

Figure 13. Photomicrograph (SEM) of Transverse Surface of Lodgepole Pine, Colorado (IPC 3033-34). Latewood Tracheids (LT), Earlywood Tracheids (ET). Magnification 200 Diameters

Weight Factor Determination

The results of weight factor determinations made on pulps prepared from lodgepole pine are recorded in Table X.

TABLE X

WEIGHT FACTOR DETERMINATIONS ON LODGEPOLE PINE PULP SAMPLES

Pulp Sample	Weight Factor Determination, Analyst A	Analyst B	Av.
1. Lodgepole pine (Montana) — unbleached kraft — Hammermill Paper Co.	0.81	0.79	0.80
2. Lodgepole pine (Colorado) — unbleached kraft — IPC No. 3033-34	0.82	0.83	0.82

The overall agreement of results between analysts for the two pulp samples of lodgepole pine is very good. The factor of 0.8, although slightly lower, is in fairly good agreement with the factor of 0.9 listed in TAPPI Standard T 401 m-60. There is no difference in weight factor between these two pulps due to origin of species. Pulps prepared from lodgepole pine are not as coarse as pulps prepared from some of the other hard pines such as most species of southern yellow pine, jack pine, etc.

A photomicrograph of the fiber furnish of a pulp sample prepared from lodgepole pine is illustrated in Fig. 14.

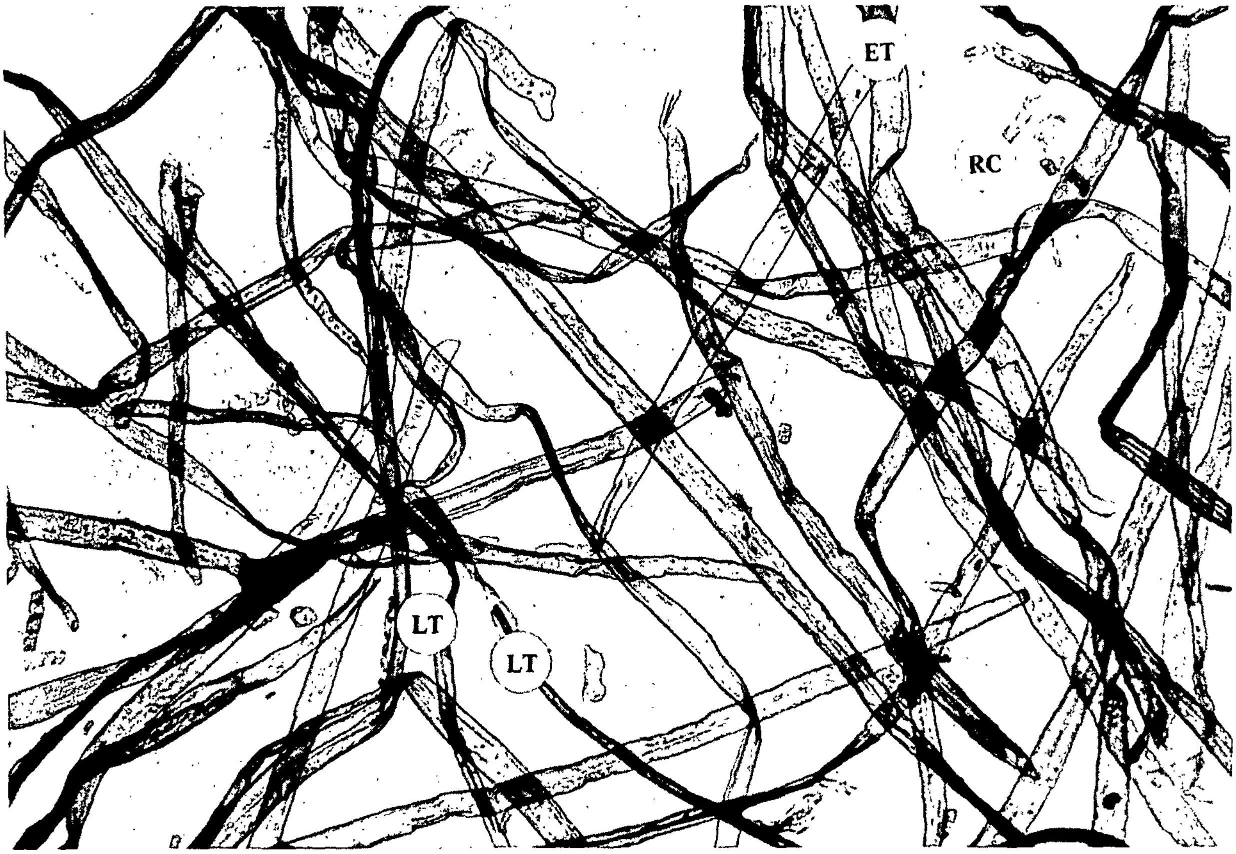

Figure 14. Pulp Sample of Lodgepole Pine, Colorado (IPC 3033-34) — Unbleached Kraft. Yield 44.4%. Kappa No. 19.5. Weight Factor 0.81. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

JACK PINE (Pinus banksiana Lamb.)

General Description and Minute Anatomy

The wood of jack pine is moderately heavy (sp.gr. approximately 0.40 green, 0.46 ovendry). The growth rings are distinct, delineated by a band of dark-colored latewood. The transition from earlywood to latewood is fairly abrupt. The earlywood zone is variable in width and is usually much wider than the denser latewood zone. The rays are very fine and not visible to the naked eye. Parenchyma cells are absent. Longitudinal (80-95 μm in width) and transverse (less than 45 μm in width) resin canals with thin-walled epithelium are present. Canals in the heartwood are frequently occluded with tylosoids. The tracheids are up to

45 mm (average 27-37 μm) in diameter and 3.5 mm (1.5 to 5.7 mm) in length. The rays are of two types, uniseriate and fusiform. The uniseriate rays are 1-8+ cells in height and are numerous. The scattered fusiform rays with a transverse resin canal are 2-3 seriate through the central thickened portion and 10 plus cells in height in the uniseriate margins. Ray tracheids are present in both types of rays, the low rays frequently consisting entirely of ray tracheids.

A photomicrograph (SEM) of the transverse surface area of jack pine is illustrated in Fig. 15.

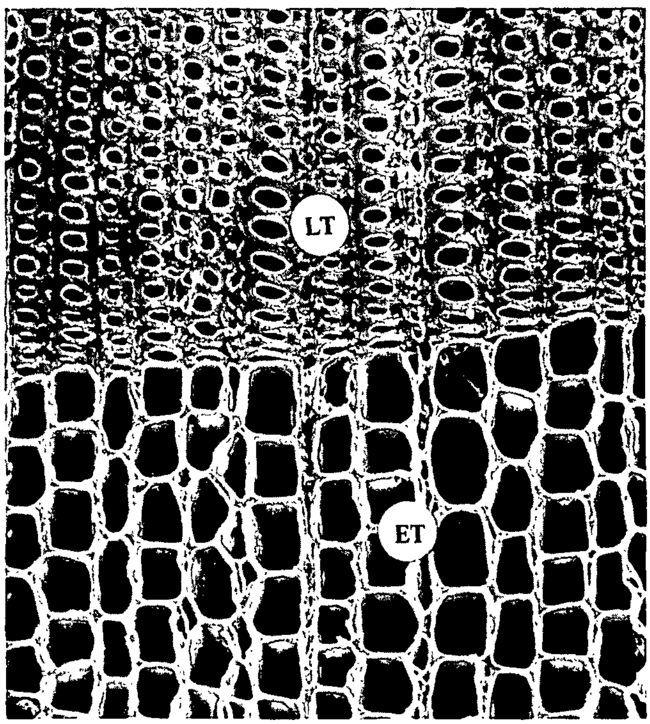

Figure 15. Photomicrograph (SEM) of Transverse Surface of Jack Pine, Wisconsin (IPC 3033-12). Latewood tracheids (LT), Earlywood Tracheids (ET). Magnification 200 Diameters

Weight Factor Determination

Weight factor determinations made on pulps prepared from species of jack pine are shown in Table XI.

TABLE XI

WEIGHT FACTOR DETERMINATIONS ON JACK PINE PULP SAMPLES

Pulp Sample	Weight Factor Determination: Analyst A	Analyst B	Av.
1. Jack pine (North Central) — unbleached kraft — Hammermill Paper Co.	1.00	0.98	0.99
2. Jack pine (Ontario) — unbleached kraft — Riegel Paper Co. No. 403	0.78	0.80	0.79
3. Jack pine (Michigan) — unbleached kraft — Scott Paper Co.	0.91	0.93	0.92
4. Jack pine (Wisconsin) — unbleached kraft — IPC No. 3033-12	0.96	0.97	0.96

The average weight factor of 0.9 determined for the furnishes of the various pulp samples is in agreement with the suggested factor (0.9) in the TAPPI Standard. Again, there appears to be no significant difference in weight factor, due to the origin of the wood species, for the few samples examined. The coarseness value of jack pine pulps is similar to pulps prepared from Virginia pine. They are not as coarse as most species of southern yellow pine (i.e., species of slash, loblolly, longleaf, and shortleaf) but would have slightly higher coarseness values than pulps prepared from species of lodgepole pine.

A photomicrograph of a pulp furnish prepared from jack pine is illustrated in Fig. 16.

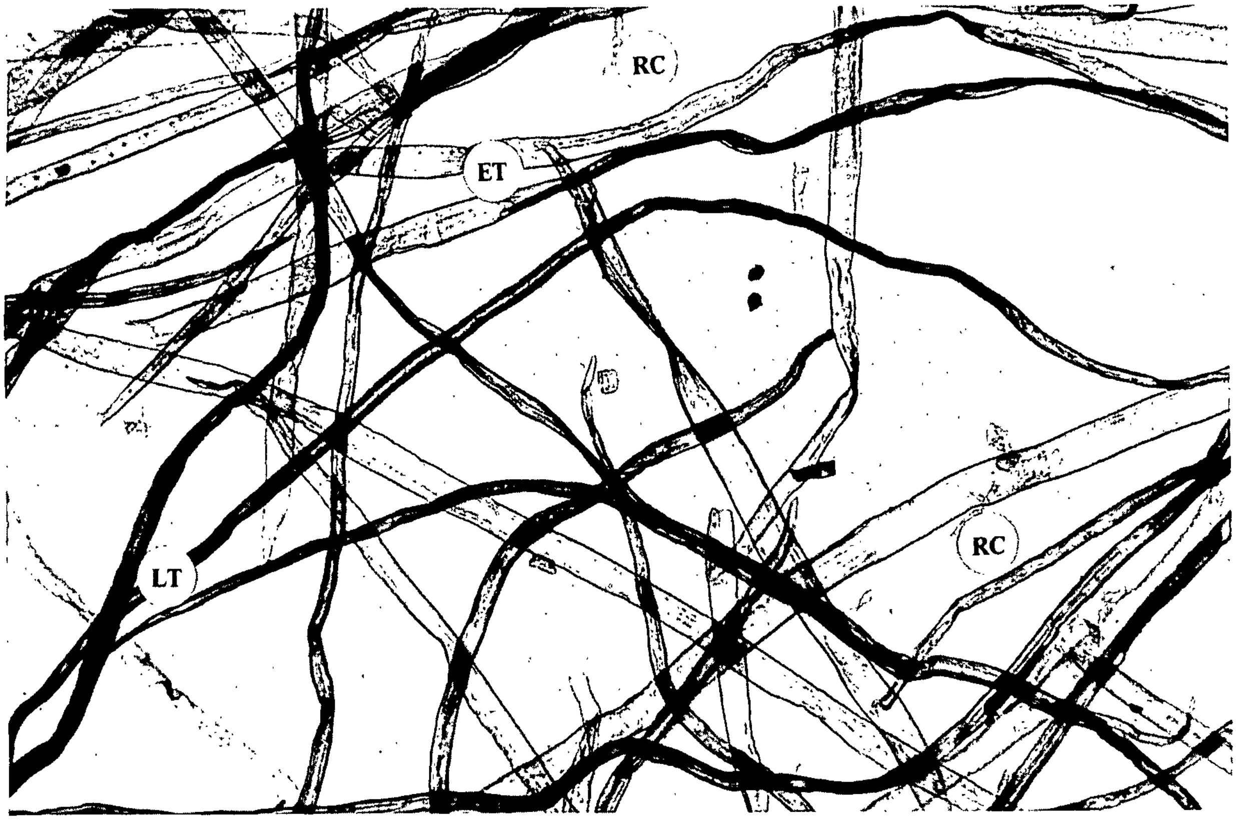

Figure 16. Photomicrograph of Pulp Sample of Jack Pine, Mich. (Scott Paper Co.) — Unbleached Kraft. Screened Yield 45.4%. Kappa No. 20.6. Weight Factor 0.92. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

VIRGINIA PINE (Pinus virginiana Mill.)

General Description and Minute Anatomy

The gross features and microscopic structure of the wood of Virginia pine is similar to that of other yellow or hard pine species of Southeastern and Eastern United States. The wood contained in species of southern yellow pine (slash, loblolly, shortleaf, pitch, pond, Virginia, etc.) is moderately heavy to heavy (average sp.gr. 0.45-0.56 green, 0.52-0.66 ovendry). The growth rings in the species are distinct, delineated by pronounced bands of thick-walled latewood fibers. The transition from earlywood to latewood is very abrupt and the widths of each vary within limits. The earlywood zone varies from very wide (slash pine, loblolly pine) to narrow (slow growth shortleaf pine, etc.) while the latewood zone ranges from broad to narrow, varying greatly in width and density, depending upon the age of the tree, conditions of growth and, within general limits, according to species. The rays are very fine and not visible (cross section) to the naked eye, except where they include a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. Parenchyma cells are not visible. Both longitudinal (average 90-150 μm in diameter) and transverse (usually less than 70 μm in diameter) resin canals with thin-walled epithelium are present. Canals in the heartwood are frequently occluded with tylosoids. The tracheids are up to 60 (average 34-45) μm in diameter. The average length of the tracheids of longleaf, shortleaf, and slash pine is 4.5-5.0 mm while that of loblolly is 3.5-4.0 mm, pond 3.0 mm and Virginia 2.0-2.5 mm. The rays are of two types uniseriate and fusiform. The uniseriate rays are numerous and 1 to 8+ cells high. The fusiform rays are scattered, with a horizontal resin canal 2-4 seriate in the central portion, tapering to a uniseriate margin up to 12+ cells high. Ray tracheid are present in both types of rays and are marginal and interspersed. The ray parenchyma are thin walled. The volume occupied by the rays averages approximately 8.4%.

The yellow or hard pines of Southeastern and Eastern United States cannot be separated on the basis of wood structure. A photomicrograph of the transverse surface prepared from a wood sample of Virginia pine is illustrated in Fig. 17.

Weight Factor Determination

Weight factor determinations made on pulp samples prepared from Virginia pine are listed in Table XII. The two trees used in this comparison were checked for specific gravity and had values of 0.40 and 0.43. These values are slightly lower than normal and apparently reflect the young age of the trees involved (21 and 25 years).

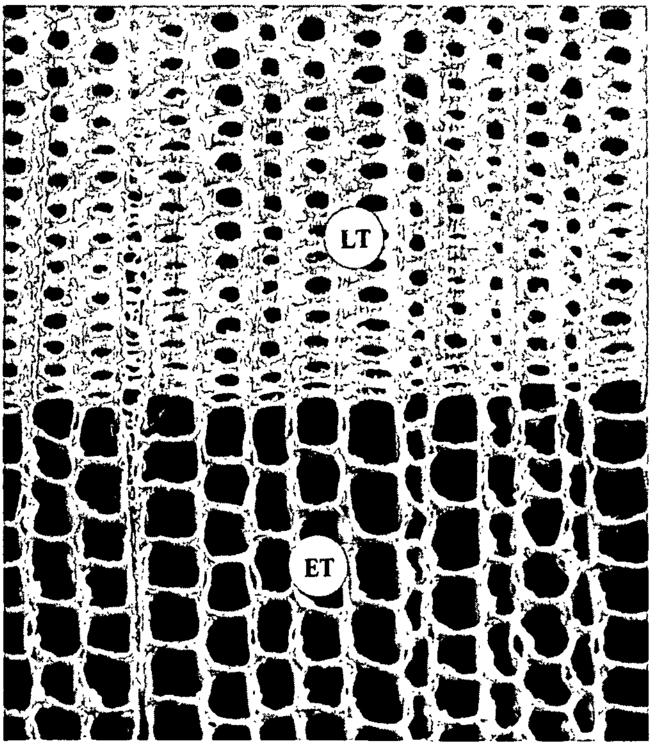

Figure 17. Photomicrograph (SEM) of Transverse Surface of Virginia Pine, N. Carolina (IPC 3033-36). Latewood Tracheids (LT), Earlywood Tracheids (ET). Magnification 200 Diameters

TABLE XII

WEIGHT FACTOR DETERMINATIONS ON VIRGINIA PINE PULPS

Pulp Samples	Weight Factor Determination, Analyst A	Weight Factor Determination, Analyst B	Weight Factor Determination, Av.
1. Virginia pine (Penn.) — unbleached kraft — IPC No. 3033-35	1.02	1.00	1.01
2. Virginia pine (N. Carolina) — unbleached kraft — IPC No. 3033-36	1.04	1.00	1.02

Pulps prepared from Virginia pine are not as coarse as pulps prepared from other species of southern yellow pine and, therefore, have lower weight factor values. A weight factor of 1.0 is recommended for Virginia pine pulps compared with an average factor of approximately 1.5 for pulps prepared from other species of southern yellow pine. There is no significant difference in weight factor due to geographic origin.

A photomicrograph of the fiber furnish of a pulp sample prepared from Virginia pine is illustrated in Fig. 18.

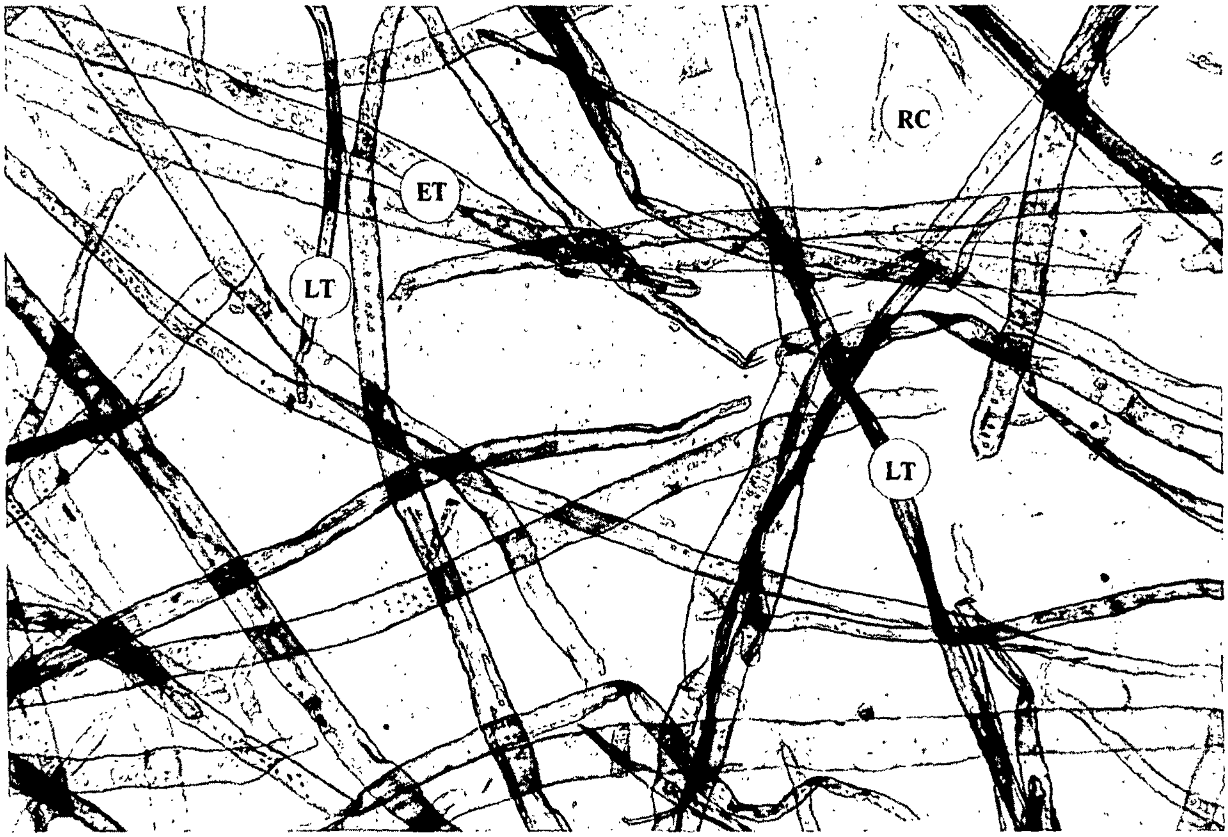

Figure 18. Pulp Sample of Virginia Pine, Penn. (IPC 3033-35) — Unbleached Kraft. Yield 47.3%. Kappa No. 51.7. Weight Factor 1.01. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

RED PINE, NORWAY PINE (<u>Pinus resinosa</u> Ait.)

<u>General Description and Minute Anatomy</u>

The wood of red pine is moderately heavy (sp.gr. approximately 0.41 green, 0.44 ovendry). The growth rings are distinct, delineated by a band of darker latewood, narrow to wide. The transition from early- to latewood is more or less abrupt, the earlywood zone generally wide, the latewood zone narrow to fairly wide. Rays are very fine, not visible on the cross section to the naked eye. Resin canals with thin-walled epithelium, frequently occluded with tylosoids in the heartwood, are smaller than in most pines. The longitudinal canals have a maximum diameter of 120 (average 80-110) μm while the transverse canals are much smaller (usually less than 50 μm). The tracheids average 30 to 40 μm in diameter and 3.4 (1.2 to 5.2) mm in length. Rays are of two types, uniseriate and fusiform. The uniseriate rays are numerous, 1-10+ cells in height. Fusiform rays are scattered with a transverse resin canal, 2-3 seriate through the central thickened portion, tapering more or less abruptly above and below to uniseriate margins up to 10+ cells in height. Ray tracheids are present in both types of rays. Longitudinal parenchyma is absent.

Weight Factor Determinations

Weight factor determinations made on a pulp sample prepared from species of red pine are shown in Table XIII.

TABLE XIII

WEIGHT FACTOR DETERMINATIONS MADE ON RED PINE PULP SAMPLE

Pulp Sample	Weight Factor Determination, Analyst A	Weight Factor Determination, Analyst B	Weight Factor Determination, Av.
Red pine (Michigan) — unbleached kraft — Scott Paper Co.	0.92	0.87	0.90

Although the study was limited, the factor of 0.9 obtained for the submitted pulp sample is in agreement with the recommended TAPPI Standard for pulps prepared from this species.

A photomicrograph of the pulp furnish is illustrated in Fig. 19.

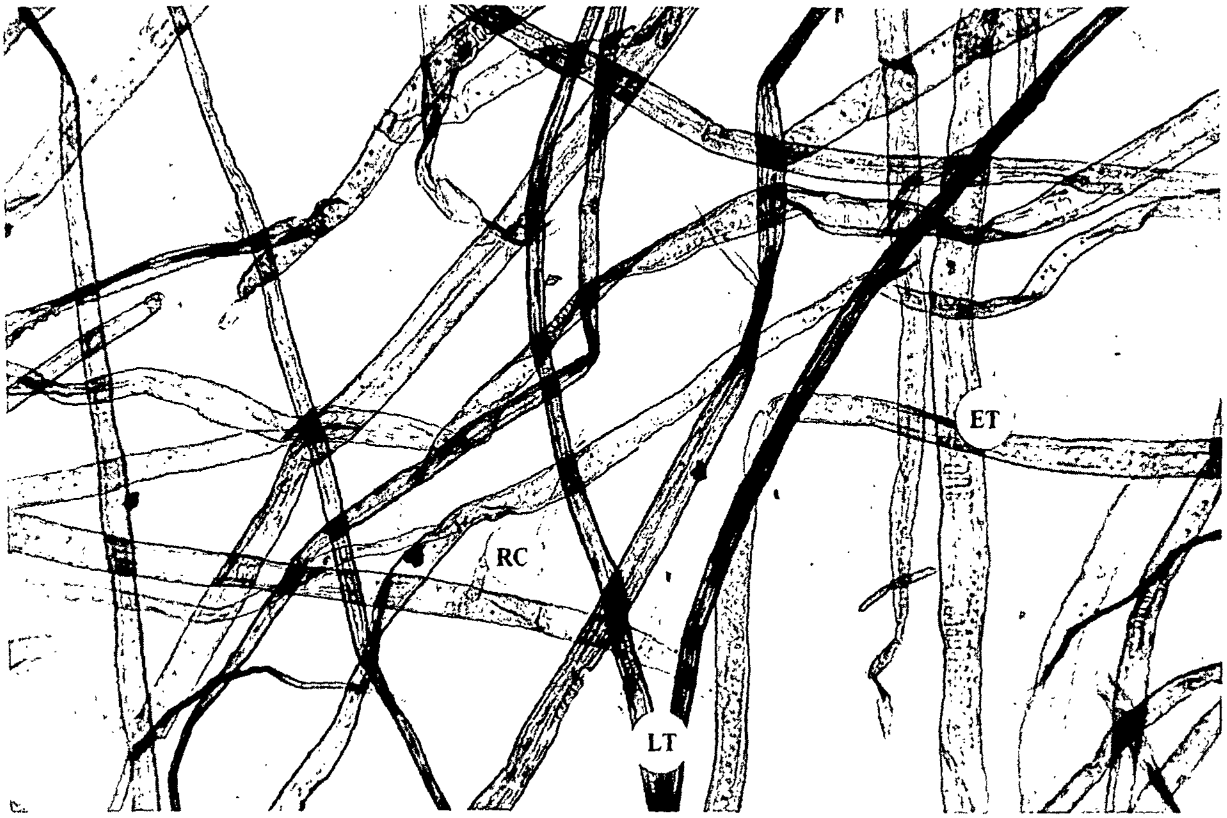

Figure 19. Pulp Sample of Red Pine, Mich. (Scott Paper Co.) — Unbleached Kraft. Screened Yield 45.9%. Kappa No. 21.0. Weight Factor 0.90. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

TAMARACK, EASTERN LARCH [Larix laricina (Du Roi) K. Koch]

General Description and Minute Anatomy

The wood of tamarack is moderately heavy (sp.gr. approximately 0.49 green, 0.53 ovendry). The growth rings are distinct, delineated by a pronounced band of darker-colored latewood. The transition from earlywood to latewood is abrupt. The earlywood zone usually occupies three-fourths or more of the ring. The rays are very fine and not distinct to the naked eye. Longitudinal (60-90 µm in diameter) and transverse (less than 25 µm in diameter) resin canals with thick-walled epithelial cells and few tylosoids are present. The tracheids are up to 45 (average 25-35) µm in diameter and 3.6 mm (1.7 to 5.6 mm) in length. The rays are two types, uniserieate or rarely in part biseriate and fusiform. The uniseriate cells are numerous and 1-16 plus cells in height. The biseriate cells are sparse and scattered or wanting. The fusiform rays are 2-3 seriate in the central portion, tapering to uniseriate margins up to 16+ cells in height. Ray tracheids are present in both types of rays and are marginal or but rarely interspersed. Longitudinal parenchyma is terminal and very sparse or wanting.

Weight Factor Determinations

The results of weight factor determinations made on pulp samples prepared from species of tamarack are shown in Table XIV.

TABLE XIV

WEIGHT FACTOR DETERMINATIONS ON TAMARACK PULP SAMPLES

Pulp Sample	Weight Factor Determination, Analyst A	Analyst B	Av.
1. Tamarack — sodium bisulfite — Great Northern Paper Co.	1.10	1.10	1.10
2. Tamarack (Michigan) — unbleached kraft — Hammermill Paper Co.	1.00	1.02	1.01

The tamarack pulps represent two types of pulping processes (sodium bisulfite and kraft). The sodium bisulfite pulp contained a fairly large percentage of shives and, as might be expected, appeared to have a higher coarseness and had a correspondingly higher weight factor value. Weight factors of 0.9-1.0 are recommended for most bleached and unbleached chemical pulps prepared from this wood species.

A photomicrograph of a pulp furnish prepared from tamarack is illustrated in Fig. 20.

Figure 20. Pulp Sample of Tamarack (Great Northern Paper Co.) — Unbleached Sodium Bisulfite. Total Yield 44.5%. Weight Factor 1.10. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

EASTERN HEMLOCK, CANADA HEMLOCK [Tsuga canadensis (L.) Carr.]

General Description and Minute Anatomy

The wood of eastern hemlock is moderately light (sp.gr. approximately 0.38 green, 0.42 ovendry). The growth rings are distinct, delineated by a pronounced band of darker latewood. The earlywood zone usually occupies two-thirds or more of the ring and the transition to latewood is generally abrupt. Parenchyma is not visible. Rays on the cross section are very fine and not distinct with the naked eye. Resin canals are absent. The tracheids are up to 45 (average 28-40) µm in diameter and average approximately 3.0 mm in length. Rays are uniseriate, 1-12+ cells in height. Ray tracheids are present, usually restricted to one row on the upper and lower margins. The volume occupied by the tracheids and rays is 94 and 6%, respectively.

Weight Factor Determinations

Weight factor determinations made on two submitted unbleached sodium bisulfite pulp samples prepared from eastern hemlock are shown in Table XV.

TABLE XV

WEIGHT FACTOR DETERMINATIONS MADE ON EASTERN HEMLOCK PULP SAMPLES

Pulp Sample	Weight Factor Determinations, Analyst A	Analyst B	Av.
1. Eastern hemlock — unbleached Na bisulfite — Cook No. 903A — Great Northern Paper Co.	0.92	0.92	0.92
2. Eastern hemlock — unbleached Na bisulfite — Cook No. 1018A — Great Northern Paper Co.	1.06	1.06	1.06

These pulps contained some shives and would be expected, therefore, to have higher coarseness and weight factor values than most unbleached and bleached chemical pulps prepared from this species. Also, Cook No. 1018A had a higher percentage yield than Cook No. 903A (73.4% *vs.* 49.6%) which would account for the higher weight factor value of this pulp. Highly significant positive correlations were obtained between weight factor and Kappa number and weight factor and screened yield in the examination of the weight factors of southern yellow pine pulp samples (Project 3033, Progress Report Two). Reducing the degree of delignification (high Kappa number) increased the pulp yield and resulted in higher than average weight factors.

A weight factor of 0.9 is recommended for most bleached and unbleached chemical pulps prepared from species of eastern hemlock.

WHITE SPRUCE [Picea glauca (Moench) Voss]

General Description and Minute Anatomy

The wood of white spruce is light to moderately light (average sp.gr. approximately 0.37 green, 0.41-0.45 ovendry). The growth rings are distinct, delineated by the contrast between the latewood and the earlywood of the succeeding ring. The earlywood zone is usually several times wider than the latewood, grading into the latewood. Parenchyma is not visible. The rays are very fine and not distinct on the cross section with the naked eye. The wood contains longitudinal resin canals with a maximum diameter of 135 (average 60-90) μm and smaller (less than 30 μm in diameter) transverse canals. The canals have thick-walled epithelium and occasionally tylosoids in the heartwood. Volume occupied by resin canals is < 0.5%. The tracheids are up to 35 (average 25-30) μm in diameter and 3.3 mm (1.3 to 4.9 mm) in length. Volume occupied is approximately 95%. The rays are of two types, uniseriate or rarely in part biseriate, and fusiform. The uniseriate rays are numerous 1-20 cells in height while the biseriate rays are very sparse and scattered on wanting. The fusiform rays are scattered with one or rarely two transverse resin canals, 2-3 seriate through the central portion, tapering above and below to uniseriate margins up to 20+ cells in height. Ray tracheids are present in both types of rays, usually restricted to one row on the upper and lower margins. The volume occupied by the rays is approximately 5%.

It is noted that the woods of white, red, black, and Engelmann spruce cannot be separated with certainty by either gross characteristics or minute anatomy.

A photomicrograph (SEM) of the transverse surface area of white spruce is illustrated in Fig. 21.

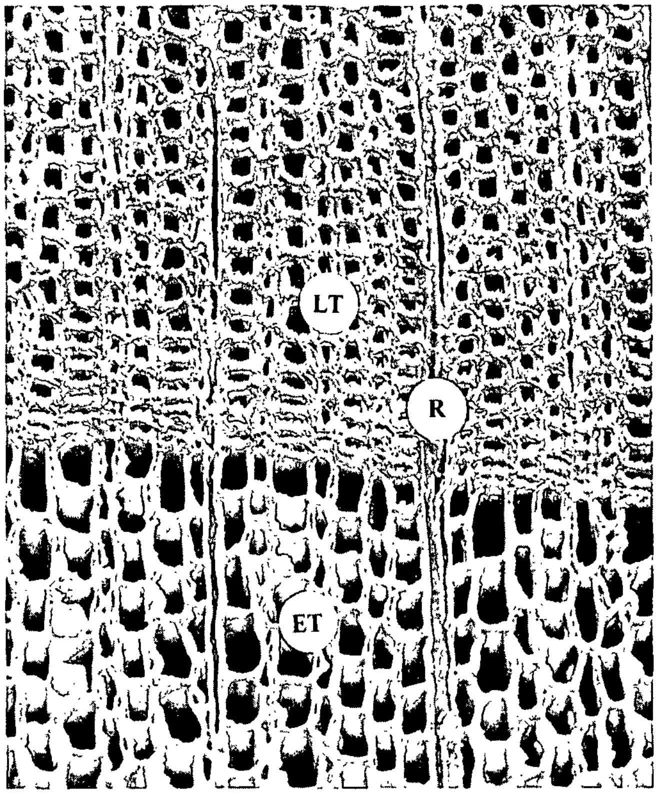

Figure 21. Photomicrograph (SEM) of Transverse Surface of White Spruce, Wis. (IPC 3033-8). Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray (R). Magnification 200 Diameters

Weight Factor Determination

Weight factor determinations made on three pulp samples prepared from species of spruce are shown in Table XVI.

TABLE XVI

WEIGHT FACTOR DETERMINATIONS ON SPRUCE PULPS

Pulp Sample	Weight Factor Determinations, Analyst A	Analyst B	Av.
1. Spruce (Maine) — unbleached Na bisulfite (No. 649) — Great Northern Paper Co.	0.91	0.84	0.88
2. Spruce (Maine) — unbleached Na bisulfite (No. 808) — Great Northern Paper Co.	0.73	0.71	0.72
3. Spruce (N. Wis.) — unbleached kraft — IPC No. 3033-8	0.74	0.69	0.72

Pulps prepared from spruce have relatively low coarseness and weight factor values. Factors of 0.8-0.9 should be appropriate for most chemical pulps prepared from this wood species.

A photomicrograph of a pulp furnish containing a mixture of white and red spruce is illustrated in Fig. 22.

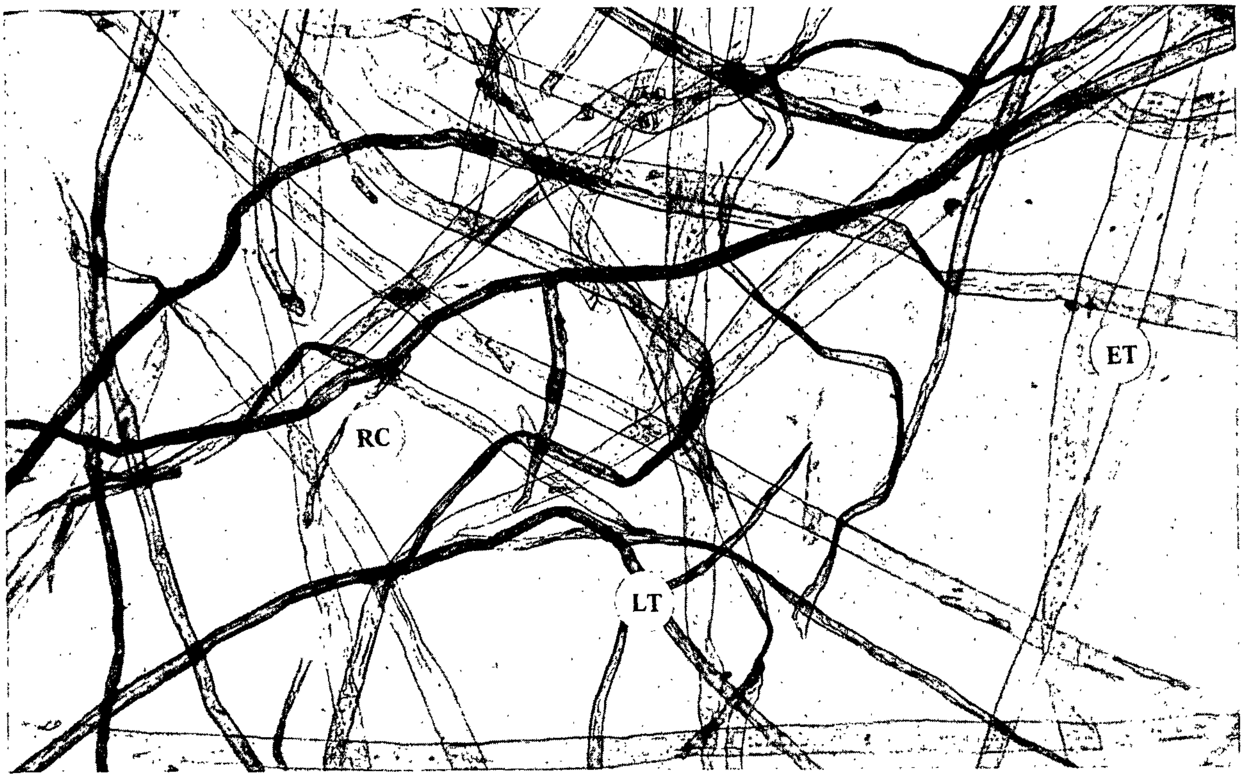

Figure 22. Pulp Sample of White and Red Spruce, Maine (Great Northern) — Unbleached Na Bisulfite. Weight Factor 0.72. Latewood Tracheids (LT), Earlywood Tracheids (LT), Ray Cells (RC). Magnification 90 Diameters

BALSAM FIR [Abies balsamea (L.) Mill.]

General Description and Minute Anatomy

The wood of the species is light (sp.gr. approximately 0.34 green, 0.38 ovendry). The earlywood usually occupies two-thirds or more of the annual ring. The transition from early to latewood is very gradual. The growth rings are distinct, delineated by the contrast between the somewhat denser latewood and the earlywood of the succeeding ring. Longitudinal parenchyma is very sparse or wanting. The rays are very fine and not distinct on the cross section to the naked eye. Normal resin canals are wanting but longitudinal wound (traumatic) canals are sometimes present. The tracheids are up to 50 (average 30-40) μm in diameter and 3.5 mm (1.9 to 5.6 mm) in length. Volume occupied is approximately 95%. The rays are uniseriate 1 to 30+ cells in height and made up wholly of ray parenchyma or rarely with a row of ray tracheids on both margins. The volume occupied by the rays is approximately 5%. The true firs (Abies spp.) cannot be separated on the basis of wood anatomy.

A photomicrograph (SEM) of the transverse surface area of balsam fir is illustrated in Fig. 23.

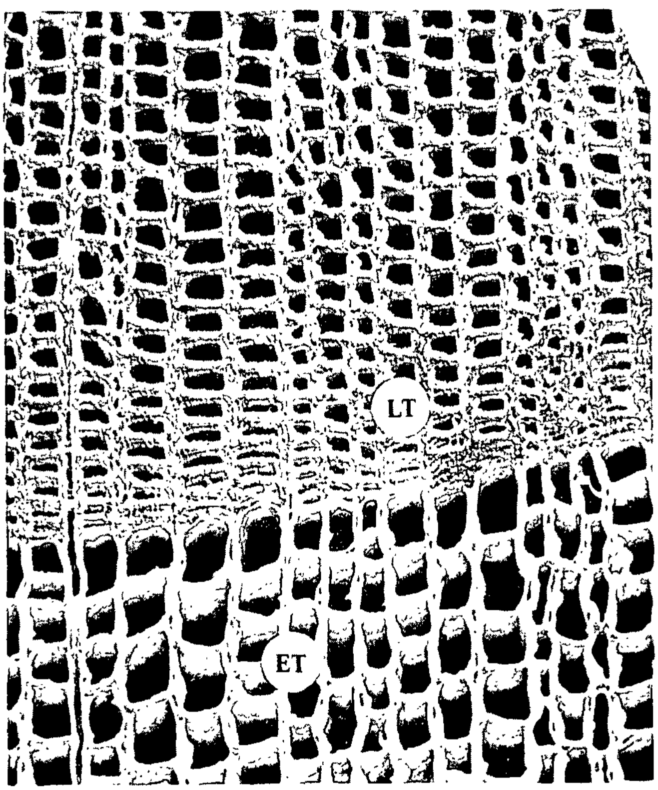

Figure 23. Photomicrograph (SEM) of Transverse Surface of Balsam Fir, Wis. (IPC 3033-30). Latewood Tracheids (LT), Earlywood Tracheids (ET). Magnification 200 Diameters

Weight Factor Determination

The results of weight factor determinations made on pulps prepared from balsam fir are shown in Table XVII.

TABLE XVII

WEIGHT FACTOR DETERMINATIONS MADE ON BALSAM FIR PULPS

Pulp Samples	Weight Factor Determination, Analyst A	Weight Factor Determination, Analyst B	Weight Factor Determination, Av.
1. Balsam fir (Maine) — unbleached Na bisulfite (No. 650) — Great Northern Paper Co.	0.84	0.82	0.83
2. Balsam fir (Maine) — unbleached Na bisulfite (No. 1017B) — Great Northern Paper Co.	1.12	1.02	1.07
3. Balsam fir (Wis.) — unbleached kraft — IPC No. 3033-30	0.84	0.81	0.82

The weight factors obtained for the Na bisulfite pulp No. 650 and the IPC pulp sample No. 3033-30 were the same. The yield of these pulps was 50.3 and 48.1%, respectively. The yield of the Na bisulfite pulp No. 1017B was 73.4% which resulted in a higher weight factor value (see the results of weight factor determinations made on eastern hemlock pulp samples).

A photomicrograph of a pulp furnish prepared from balsam fir is illustrated in Fig. 24.

Figure 24. Pulp Sample of Balsam Fir, Wis. (IPC 3033-30) — Unbleached Kraft — Weight Factor 0.82. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

NORTHERN WHITE-CEDAR, EASTERN ARBORVITAE (Thuja occidentalis L.)

General Description and Minute Anatomy

The wood of northern white-cedar is very light (sp.gr. approximately 0.29 green, 0.31 ovendry). Growth rings are distinct, delineated by a darker band of latewood which is usually narrow. The transition from early- to latewood is more or less gradual, the earlywood zone occupying most of the ring. Parenchyma is not visible. Resin canals are wanting. The rays are very fine on the cross section and form a fine, close, inconspicuous fleck on the quarter surface. The tracheids are up to 35 (average 20-30) μm in diameter and approximately 3.5 mm in length. Longitudinal parenchyma is variable in distribution, (a) sparse and often apparently wanting, or (b) abundant and banded in a given growth ring and then often wanting in neighboring rings. The ray cells are uniseriate, 1-8+

cells in height, consisting entirely of ray parenchyma or sometimes with an occasional ray tracheid. Ray cells are empty or with scanty infiltration. The wood in general is comparable to western red-cedar (*Thuja plicata* Donn), but lighter in color, finer-textured, and generally with less prominent growth rings.

Weight Factor Determination

The results of a weight factor determination made on a sample of northern white-cedar pulp are recorded in Table XVIII.

TABLE XVIII

WEIGHT FACTOR DETERMINATION FOR NORTHERN
WHITE-CEDAR PULP SAMPLE

Pulp Sample	Weight Factor Determination, Analyst A	Weight Factor Determination, Analyst B	Weight Factor Determination, Av.
Northern white-cedar — unbleached kraft — Great Northern Paper Co.	0.52	0.48	0.50

Pulps prepared from species of northern white-cedar are relatively fine when compared with pulps prepared from other species of North American softwoods. The average weight factor of 0.5 is considerably lower than the 0.9 listed in the TAPPI Standard (T 401 m-60) and a factor of 0.5-0.6 should be employed in the analysis of a sample furnish containing this pulp species.

A photomicrograph of a pulp furnish prepared from northern white-cedar is illustrated in Fig. 25.

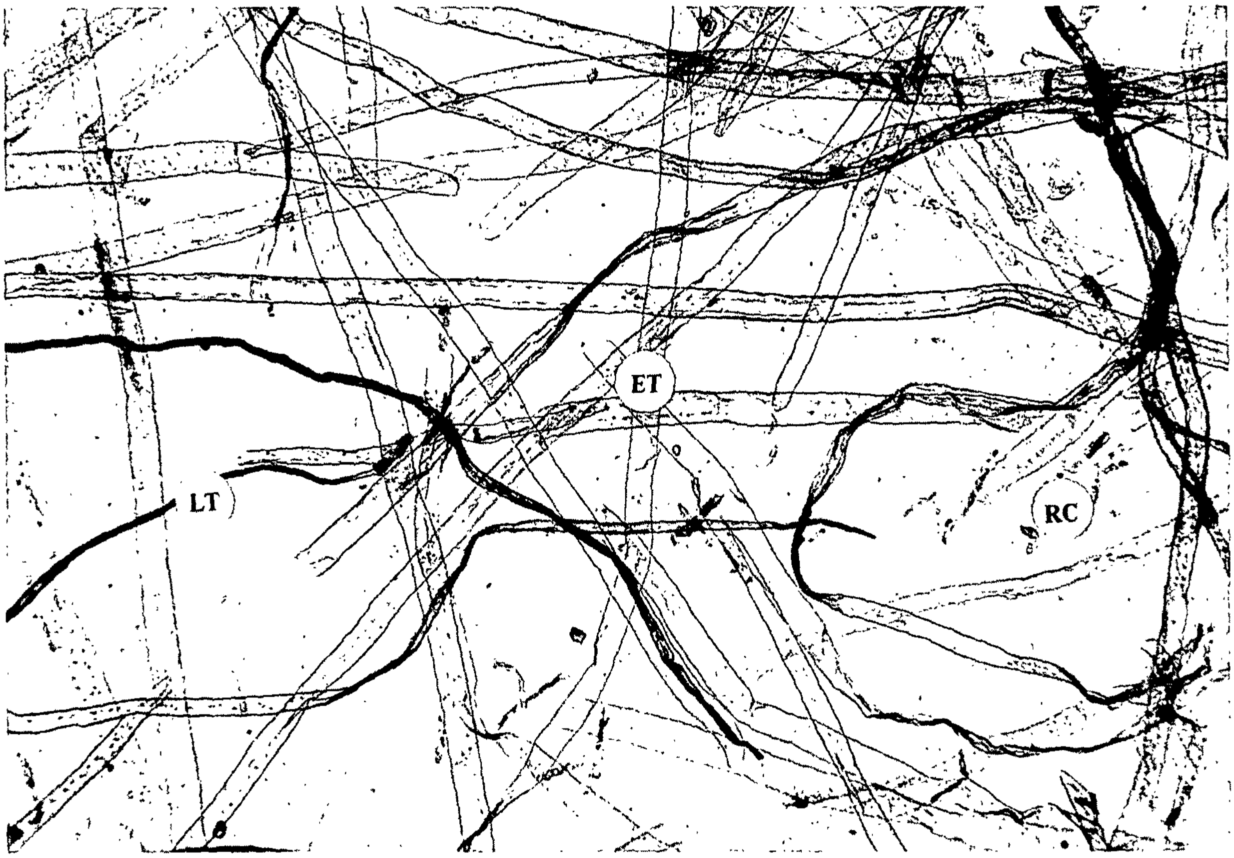

Figure 25. Pulp Sample of Northern White-cedar (Great Northern) — Unbleached Kraft. Weight Factor 0.50. Latewood Tracheids (LT), Earlywood Tracheids (ET), Ray Cells (RC). Magnification 90 Diameters

DISCUSSION OF RESULTS

A review of the results reported in previous Project 3033 reports indicated that there is a considerable variation in coarseness and, therefore, the weight factor between tree species. This current study, limited to pulps prepared from softwoods, shows weight factors ranging from 1.45 for Douglas-fir (Coastal) to 0.5 for northern white-cedar. The results of weight factor determinations made on pulps prepared from species of softwood during the present investigation are listed in Table XIX.

Figure 26 is an illustration of wood pulp fibers from various species having different coarseness and weight factor values. The fibers are aligned not in order of the average fiber length of the species but in order of decreasing coarseness and weight factor values. Fiber No. 1, for example, is from a softwood pulp sample of Parana pine having a weight factor of 2.0 and a theoretical coarseness value of 35-40. Fiber No. 6 is from a softwood pulp sample of cedar, which has a low coarseness value, 10 to 15, for a softwood pulp and a weight factor of 0.7. Pulps prepared from sweetgum, represented by fiber No. 7, are some of the coarser hardwood furnishes, having coarseness values of 10-15 and a weight factor of approximately 0.8. Fiber No. 11 represents species of maple which have the lowest coarseness value (5-10) of the more common North American hardwood pulp species. The average weight factor of maple pulps is 0.35. The theoretical relationship that is believed to exist between coarseness and weight factor is illustrated in Fig. 27.

Results of this present research indicate that: (a) there is a significant difference in the weight factor of pulps prepared from the Rocky Mountain variety of Douglas-fir and the coarser pulps prepared from the Pacific

TABLE XIX

WEIGHT FACTOR SUMMARY

Pulp No.	Pulp Sample	Total Yield, %	Kappa No.	Pulp Weight Factor Analyst A Mean	Analyst B Mean	Av.
1	Douglas-fir (Coastal) — unbleached kraft — Riegel No. 131	--	37.0	1.30	1.38	1.34
2	Douglas-fir (Coastal) — unbleached kraft — Crown Zellerbach	47.0	--	1.13	1.09	1.11
3	Douglas-fir (Coastal) — unbleached kraft — IPC No. 3033-28	41.6	20.5	1.47	1.48	1.48
4	Douglas-fir (Coastal) — kraft — IPC Project 1499	--	--	1.45	--	1.45
5	Douglas-fir (Inland) — unbleached kraft — IPC No. 3033-33	42.3	22.6	0.77	0.77	0.77
6	Douglas-fir (Inland) — kraft — IPC Project 1499	--	--	1.0	--	1.0
7	Grand fir (Wash.) — unbleached kraft — Crown Zellerbach	47.3	--	0.92	0.89	0.90
8	Noble fir (Wash.) — unbleached kraft — Crown Zellerbach	49.0	--	1.23	1.26	1.24
9	Silver fir (Wash.) — unbleached kraft — Crown Zellerbach	47.1	--	0.93	0.97	0.95
10	Western hemlock (Oregon) — unbleached kraft — Crown Zellerbach	46.4	--	1.03	0.97	1.00
11	Western hemlock (Oregon) — unbleached kraft — IPC No. 3033-27	43.6	31.2	0.80	0.79	0.80
12	Western hemlock (Wash.) — unbleached kraft — IPC No. 3033-37-38	47.6	64.8	0.83	0.84	0.84
13	Western larch (Wash.) — unbleached kraft — IPC No. 3033-29	44.7	23.5	1.20	1.22	1.21
14	Western red-cedar (Oregon) — unbleached kraft — Crown Zellerbach	48.6	--	0.70	0.69	0.70
15	Lodgepole pine (Montana) — unbleached kraft — Hammermill	--	20.0	0.81	0.79	0.80
16	Lodgepole pine (Colorado) — unbleached kraft — IPC No. 3033-34	44.4	19.5	0.82	0.83	0.82
17	Jack pine (N. Central) — unbleached kraft — Hammermill	--	19.0	1.00	0.98	0.99
18	Jack pine (Ontario) — unbleached kraft — Riegel	--	40.0	0.78	0.80	0.79
19	Jack pine (Mich.) — unbleached kraft — Scott	46.6	20.6	0.91	0.93	0.92

TABLE XIX (Continued)

WEIGHT FACTOR SUMMARY

Pulp No.	Pulp Sample	Total Yield, %	Kappa No.	Pulp Weight Factor: Analyst A Mean	Analyst B Mean	Av.
20	Jack pine (Wis.) — unbleached kraft — IPC No. 3033-12	44.5	22.2	0.96	0.97	0.96
21	Virginia pine (Penn.) — unbleached kraft — IPC No. 3033-35	47.3	51.7	1.02	1.00	1.01
22	Virginia pine (N. Carolina) — unbleached kraft — IPC No. 3033-36	47.6	55.0	1.04	1.00	1.02
23	Red pine (Mich.) — unbleached kraft — Scott	48.4	21.0	0.92	0.87	0.90
24	Tamarack — unbleached Na bisulfite — Great Northern	--	--	1.10	1.10	1.10
25	Tamarack (Mich.) — unbleached kraft — Hammermill	--	21.0	1.00	1.02	1.01
26	Eastern hemlock — unbleached Na bisulfite (Cook No. 903A) — Great Northern	49.6	--	0.92	0.92	0.92
27	Eastern hemlock — unbleached Na bisulfite (Cook No. 1018A) — Great Northern	73.4	--	1.06	1.06	1.06
28	Spruce (Maine) — unbleached Na bisulfite (Cook No. 649) — Great Northern	50.5	--	0.91	0.84	0.88
29	Spruce (Maine) — unbleached Na bisulfite (Cook No. 808) — Great Northern	50.1	--	0.73	0.71	0.72
30	Spruce (N. Wis.) — unbleached kraft — IPC No. 3033-8	40.7	20.8	0.74	0.69	0.72
31	Balsam fir (Maine) — unbleached Na bisulfite (Cook No. 650) — Great Northern	50.3	--	0.84	0.82	0.83
32	Balsam fir (Maine) — unbleached Na bisulfite (Cook No. 1017B) — Great Northern	75.5	--	1.12	1.02	1.07
33	Balsam fir (Wis.) — unbleached kraft — IPC No. 3033-30	48.1	29.7	0.84	0.81	0.82
34	Northern white-cedar (No. 654) — unbleached kraft — Great Northern	47.0	--	0.52	0.48	0.50

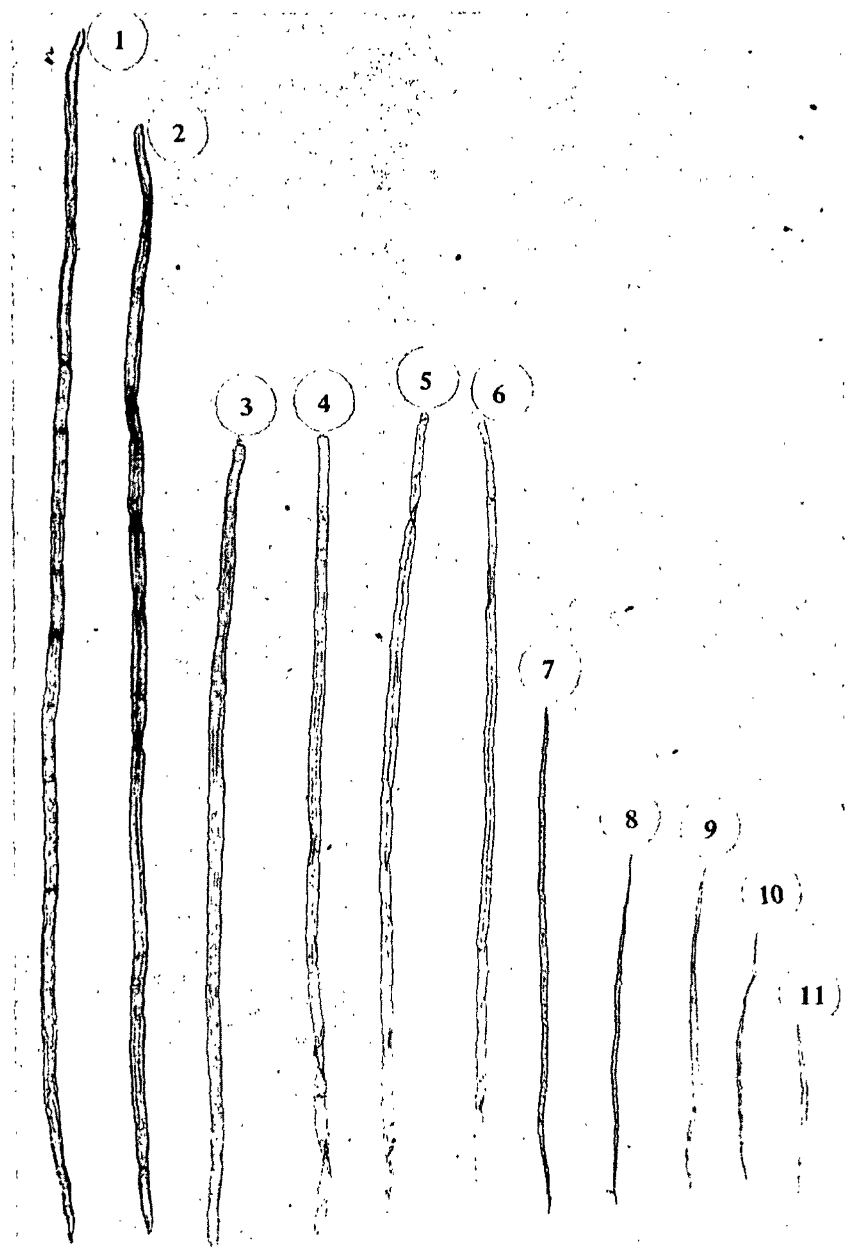

Figure 26. Softwood Pulp Fibers (1-6) and Hardwood Pulp Fibers (7-11) Aligned in Order of Decreasing Coarseness and Weight Factor Values. Parana Pine (1), Southern (Slash) Yellow Pine (2), Douglas-fir (Pacific Coast Type) (3), Western Hemlock (4), White Spruce (5), Cedar (6), Sweetgum (7), Paper Birch (8), Trembling Aspen (9), Oak (10), Maple (11)

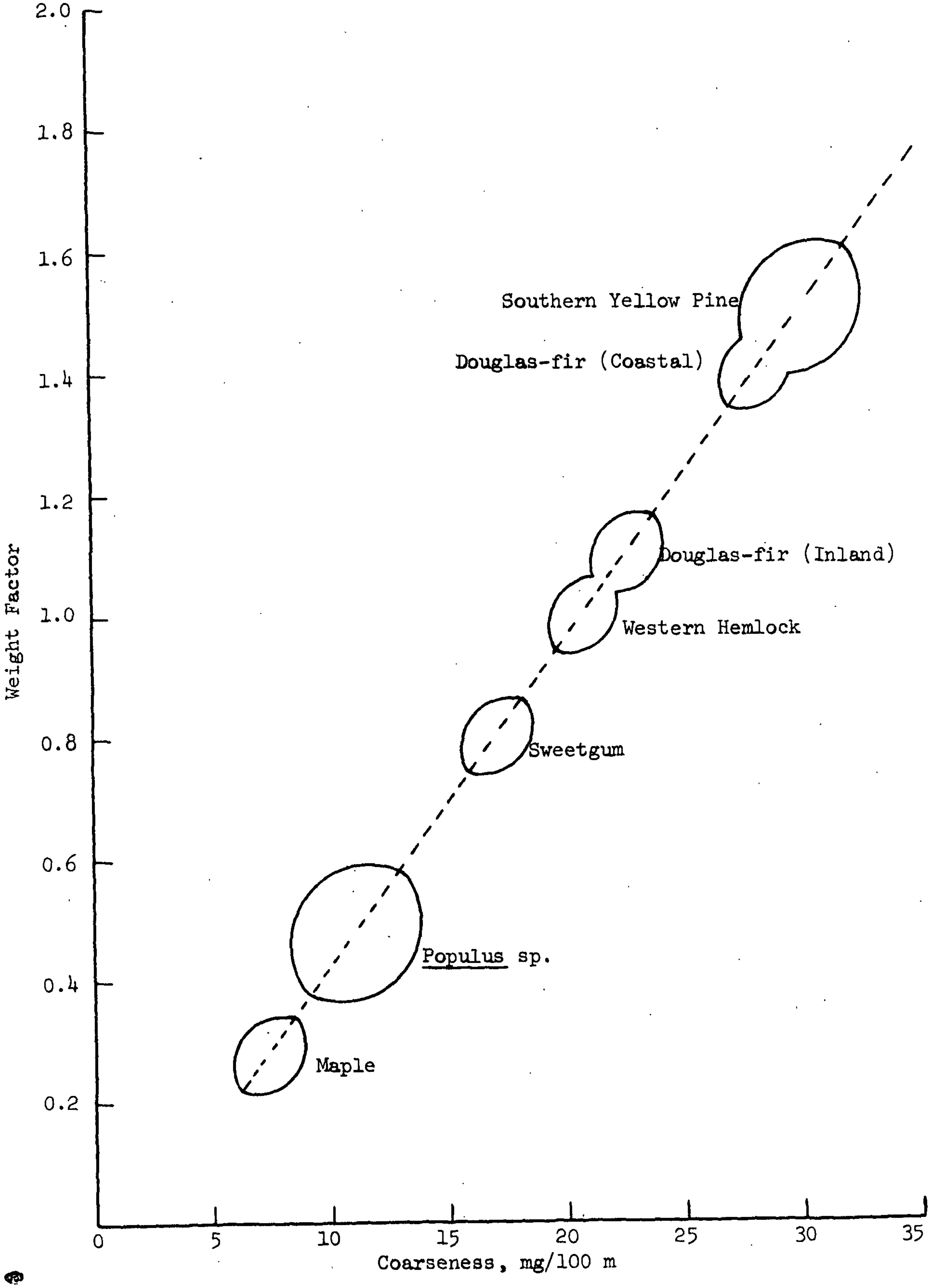

Figure 27. Theoretical Relationship of the Weight Factors of Wood Pulp Species to Their Coarseness Values

Coast variety of the species; (b) there is an indication that the weight factor values of pulps prepared from the western firs are greater than factors of similar pulps prepared from eastern balsam fir (Abies balsamea) and pulps prepared from noble fir are possibly coarser than pulps prepared from other species of western fir; (c) western larch pulps have higher weight factor values than tamarack (eastern larch); (d) pulps prepared from species of Virginia pine have a significantly lower weight factor than pulps prepared from most of the other yellow pine species (i.e., slash, loblolly, longleaf, shortleaf pine); (e) the suggested (TAPPI Standard T 401 m-60) factors of 1.2 for western hemlock and 0.9 for cedar pulps are probably too high for many chemical pulps prepared from these species; (f) there were insufficient data available to evaluate the influence of site and geographic location on weight factor, other than the previously cited instances for Douglas-fir, oak, jack pine, and the southern pines; (g) the weight factors determined on Na bisulfite pulps (tamarack, hemlock and balsam fir) substantiate earlier findings on southern pine pulps, that weight factor is influenced by the degree of cook.

Every pulp furnish of a paper or board sample has its own individual weight factor. The information and data obtained in this study should be helpful in the proper selection of weight factors in fiber analysis work. To assist the analyst in the selection of the most appropriate weight factor, Table XX, a summary of Project 3033 weight factor values, has been included. It is emphasized that wherever possible and practicable, and when a high degree of accuracy is required, weight factors should be determined for the actual pulps present in a sample furnish.

The need to identify and evaluate hardwood mixtures is expected to be an increasing problem. Included is a summary (Table XXI) of the newly calculated

TABLE XX

PROJECT 3033 RECOMMENDED WEIGHT FACTOR VALUES

Species	Weight Factor Values[a] Range	Recommended
Hardwoods		
Ash, white	0.38[b]	0.40
Beech	0.50-0.54	0.55
Birch	0.52-0.60	0.60
Gum		
Sweet	0.73-0.90	0.80
Black	0.71-0.73	0.75
Hickory	0.34[b]	0.35
Maple (red, soft)	0.30-0.37	0.35
Oak (white, red)	0.45-0.50	0.45
Populus sp. (aspen, cottonwood)	0.38-0.50	0.45
Yellow poplar	0.70-0.74	0.70
Softwoods		
Cedar		
Northern white	0.50[b]	0.60
Western red	0.70[b]	0.70
Douglas-fir		
Coastal	1.34-1.48	1.40
Inland	0.77-1.0	0.90
True firs		
Balsam	0.82-1.07	0.85
Grand and silver	0.90-0.95	0.95
Noble	1.24[b]	1.20
Hemlock		
Eastern	0.92-1.06	0.90
Western	0.80-1.00	1.00
Larch		
Eastern (tamarack)	1.01-1.10	1.00
Western	1.21[b]	1.20
Pine		
Jack	0.79-0.99	0.90
Lodgepole	0.80-0.82	0.80
Red	0.90[b]	0.90
Southern yellow		
Longleaf	1.43[b]	1.45
Shortleaf	1.30[b]	
Loblolly	1.24-1.78	
Slash	1.30-1.95	
Virginia	1.01-1.02	1.00
Spruce	0.72-0.88	0.90

[a]Weight factor values are the range of values obtained in the Project 3033 study and the recommended values are those suggested for medium yield, medium Kappa no. pulps.

[b]Approximate values based upon only one sample.

vessel factors developed for use in determining the percentages of the different hardwood species contained in a pulp mixture. See Progress Report Three for methods of determining vessel factors.

TABLE XXI

RELATIVE FACTORS OF HARDWOOD PULPS BASED ON RATIO OF VESSEL ELEMENTS

Species	Suggested Factor
Basswood	0.2
Aspen	0.3
Populus sp.	0.5
Beech	0.5
Gum (species of blackgum and redgum)	0.6
Yellow poplar	0.6
Maple	0.8
Birch	1.4
White oak	2.0
Ash	3.0
Hickory	4.5
Red oak	6.0

PLANS

Progress Report Four is the final report for Project 3033.

Fiber coarseness, weight per unit length (mg/100 m), has been demonstrated to influence a number of important paper properties and is related to some of the same fiber parameters (length, width, cell wall thickness) as weight factor. Further research to determine more accurately the relationship between weight factor and fiber coarseness (relative grex or international denier) is strongly recommended as a logical extension of weight factor research.

ACKNOWLEDGMENTS

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GLOSSARY

Apotracheal parenchyma. Axial parenchyma typically independent of the pores or vessels. (Formerly known as metatracheal.)

Biseriate ray. Ray consisting of two rows of cells, as viewed in the tangential section.

Decigrex. Coarseness of pulp fibers. See TAPPI Suggested Method T 234 sm-60.

Epidermis. The outer single layer of cells on an organ.

Epithelium. Excreting parenchymatous tissue surrounding the cavity of resin and gum canals.

Fibril. Microscopic fibrous body of which cell walls are composed.

Fusiform ray. Spindle-shaped ray, as viewed in a tangential section of wood, containing a transverse resin canal.

Gelatinous fiber. Fiber, the inner wall of which is gelatinous, or jellylike.

Grex. International standard denier.

Paratracheal parenchyma. Parenchyma obviously associated with the vessels.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Ray. Ribbon-shaped strand of tissue extending in a radial direction.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel elements with which they are associated, and possess small bordered pits.

Tyloses. Saclike or cystlike structures that sometimes develop in a vessel and rarely in a fiber through the proliferation of the protoplast (living contents) of a parenchyma cell through a pit pair.

Tylosoids. Balloonlike structures in resin canals resembling tyloses in hardwoods.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Uniseriate. Arranged in a single row, series, or layer. Also said of a wood ray which is one cell wide in cross section.

Vasicentric. Paratracheal.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood (hardwoods), arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the common walls.